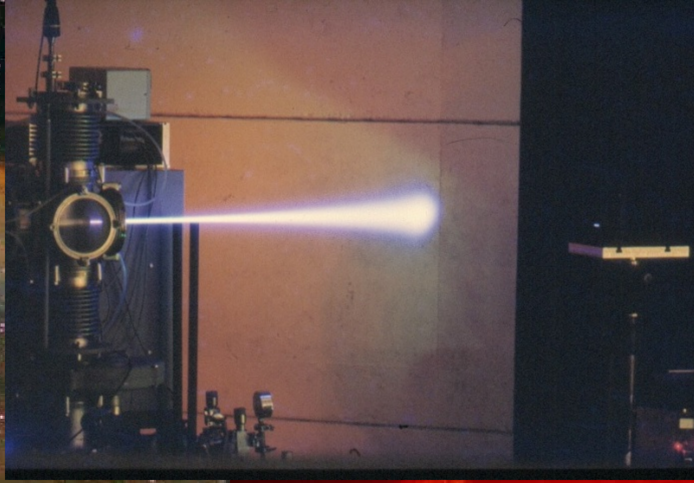
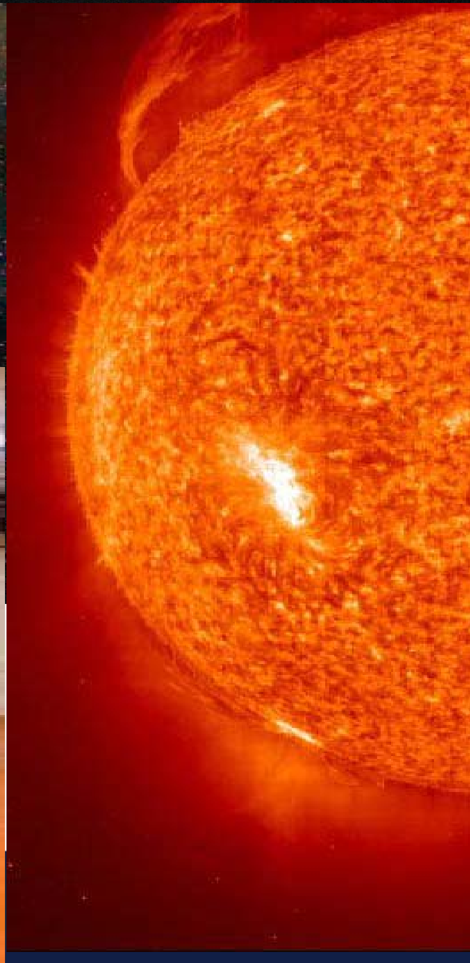
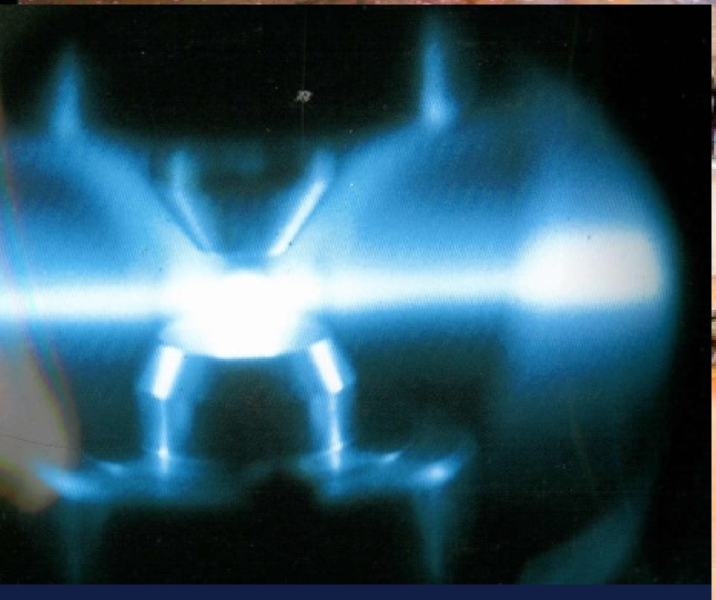
Nuclear Astrophysics Underground Status & Future

Frank Strieder
South Dakota School of Mines & Technology

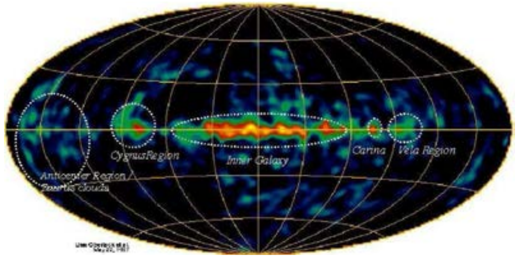
XV International Symposium on Nuclei in the Cosmos
Laboratori Nazionali del Gran Sasso, Assergi, Italy
June 25th, 2018

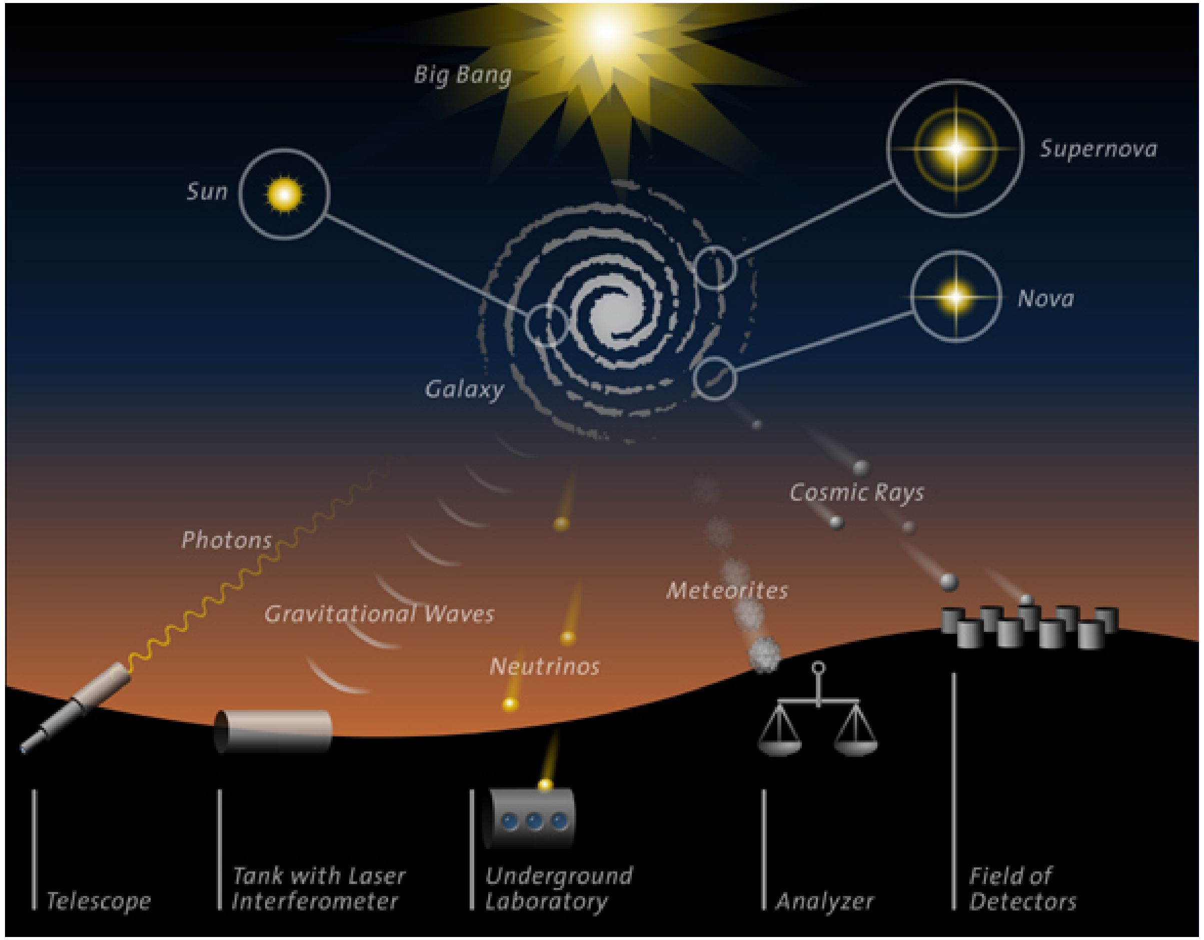


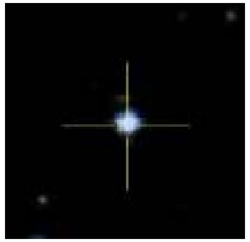


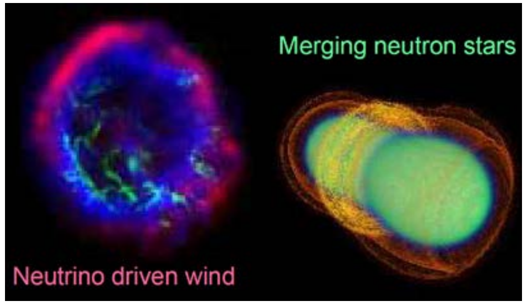


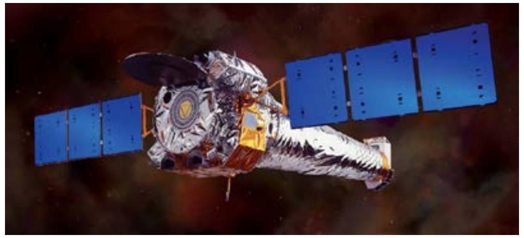
Nuclear Astrophysics is observation driven science

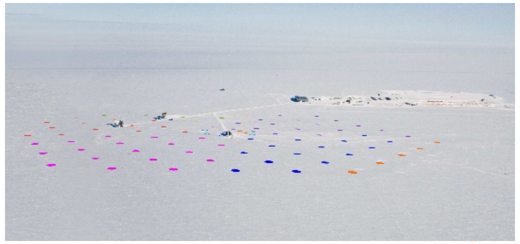




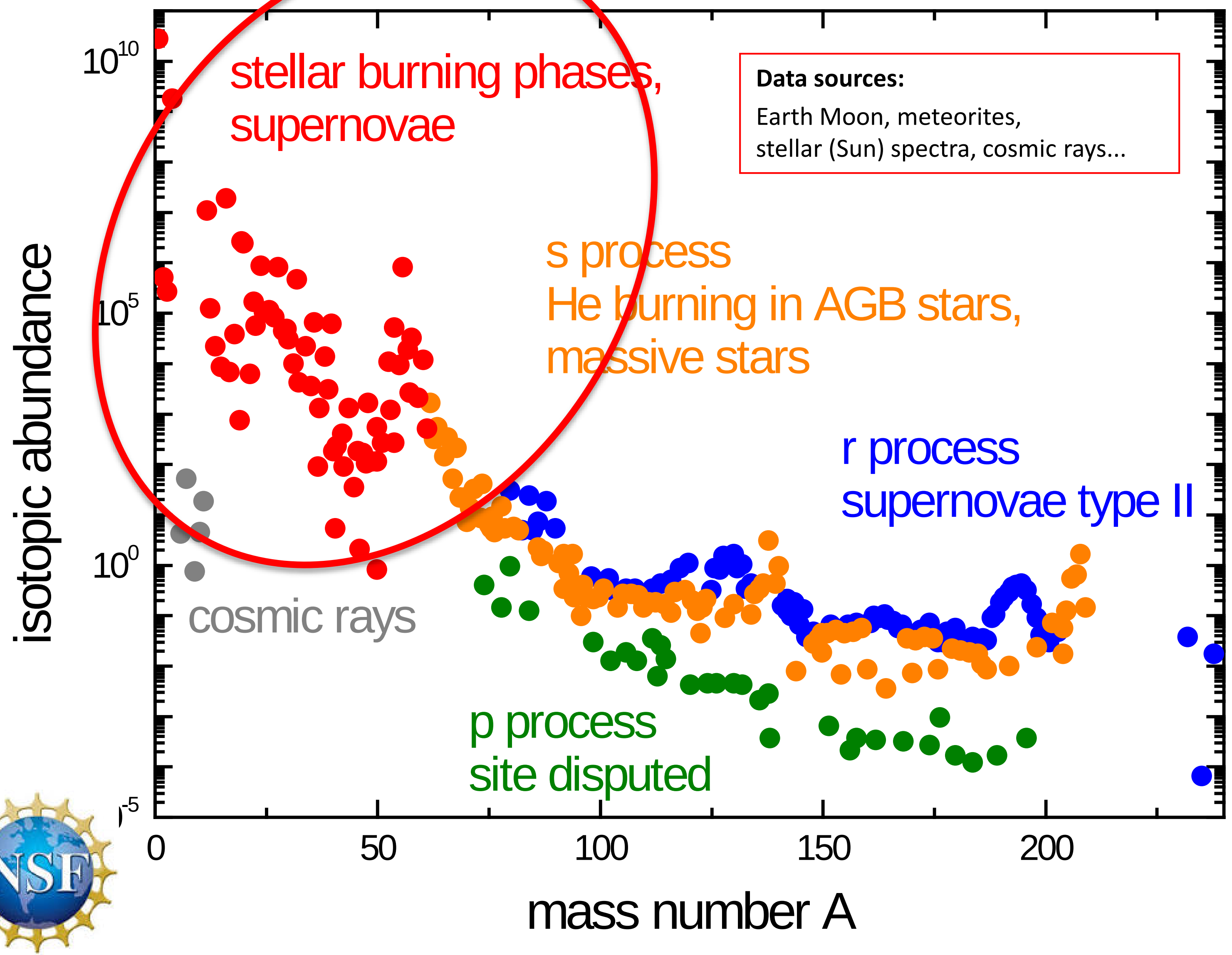


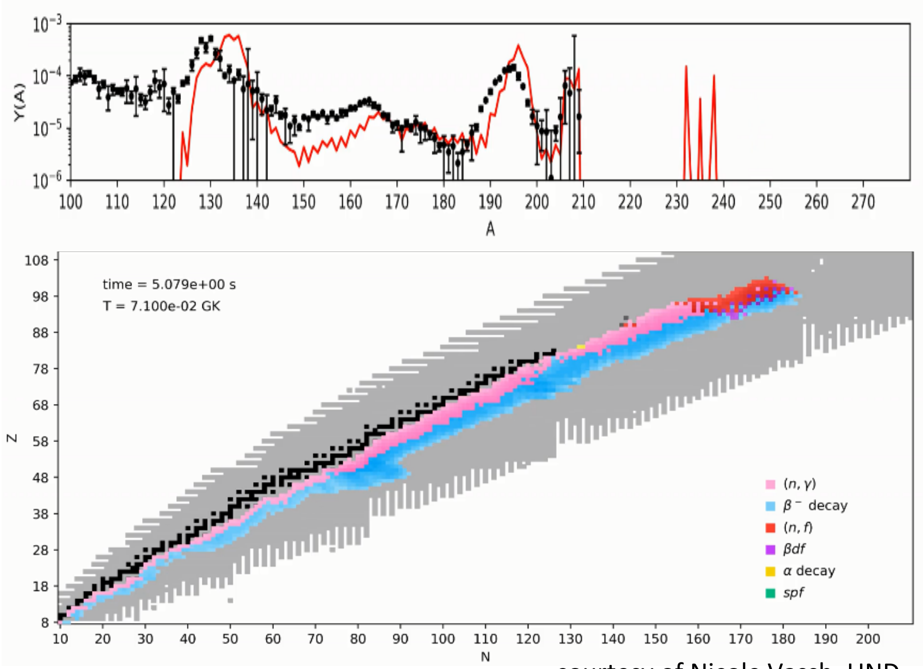




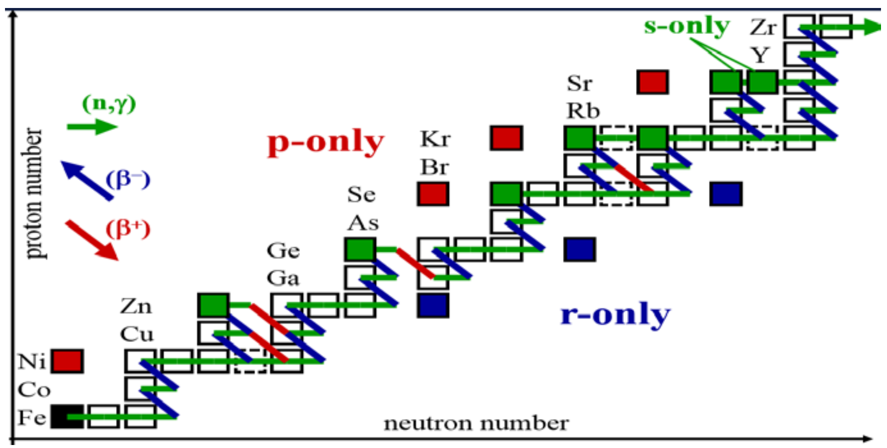


Isotopic Solar Abundances





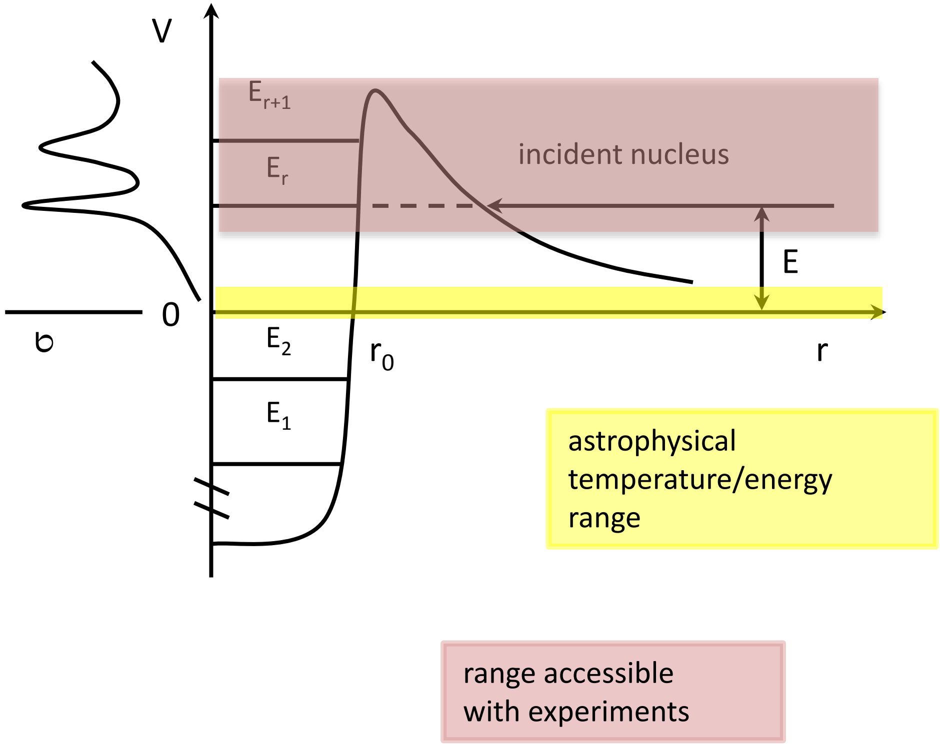
courtesy of Nicole Vassh, UND



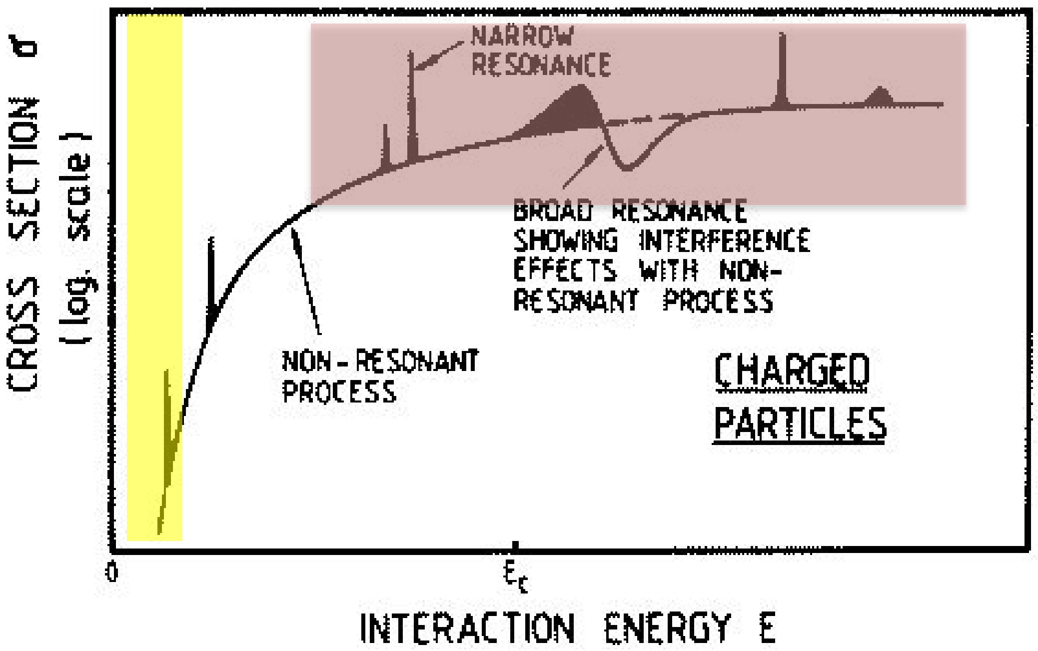
Nuclear reactions at astrophysical energies

nuclear reactions important to provide energy and the neutrons for nucleosynthesis

e.g. pp chain, $^{13}C + \alpha \rightarrow {}^{16}O + n$ or $^{22}Ne + \alpha \rightarrow {}^{25}Mg + n$

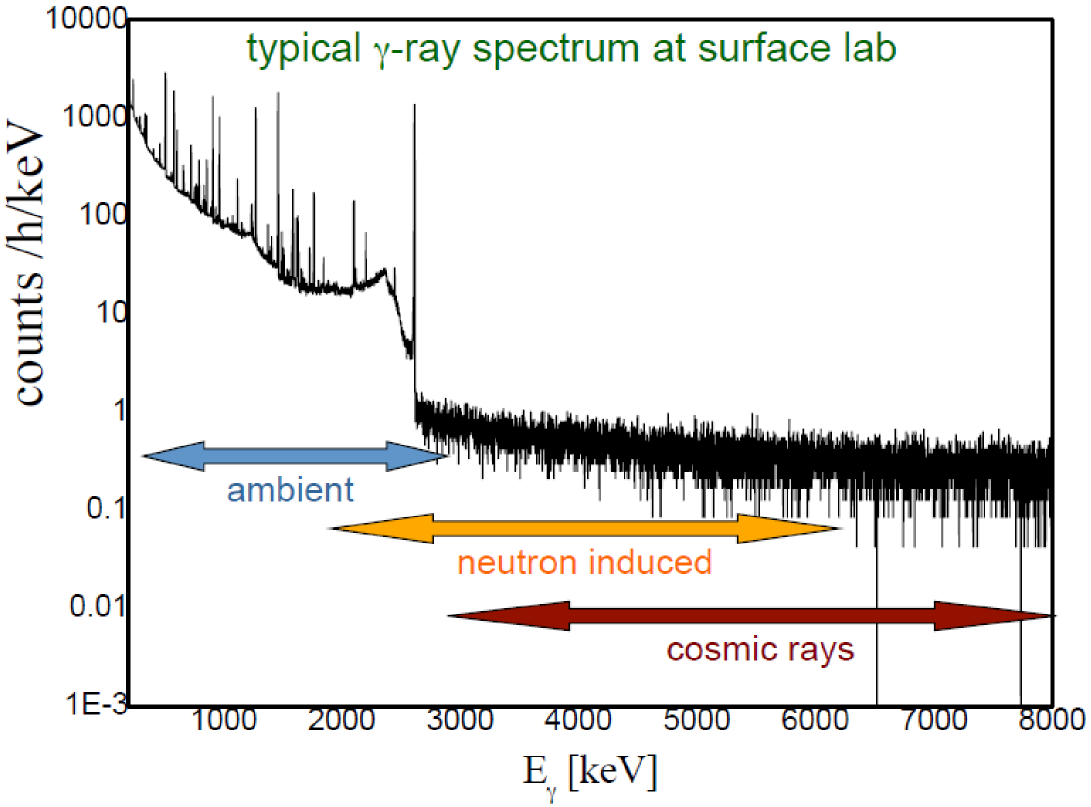


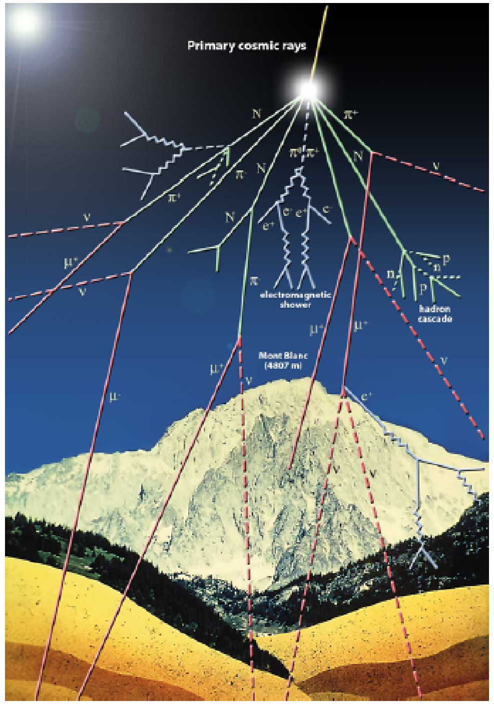
- occurs at specific energies
- cross section has STRONG energy dependence



Main Source of Background

- natural radioactivity (from U and Th chains and from Rn)
- cosmic rays
- neutrons from (α,n) reactions and fission





courtesy A. Formicola

Underground Accelerator: The Beginning

LUNA – Laboratory for Underground Nuclear Astrophysics

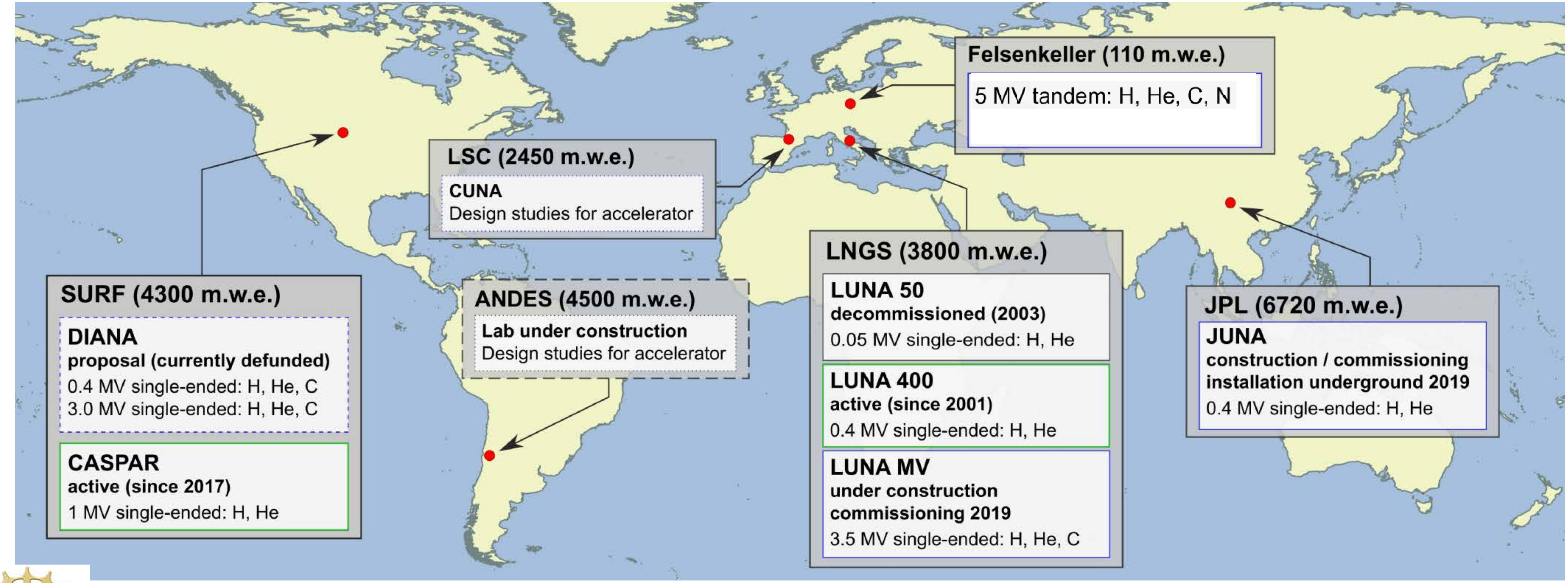
initiated: 1st Nuclei in the Cosmos Conference (Baden, Austria, 1990)

Giani Fiorentini
INFN Ferrara
Italy

Claus Rolfs
Ruhr-Universität Bochum
Germany

Why are we not going into the Gran Sasso Lab?

Nuclear Astrophysics Underground Laboratories

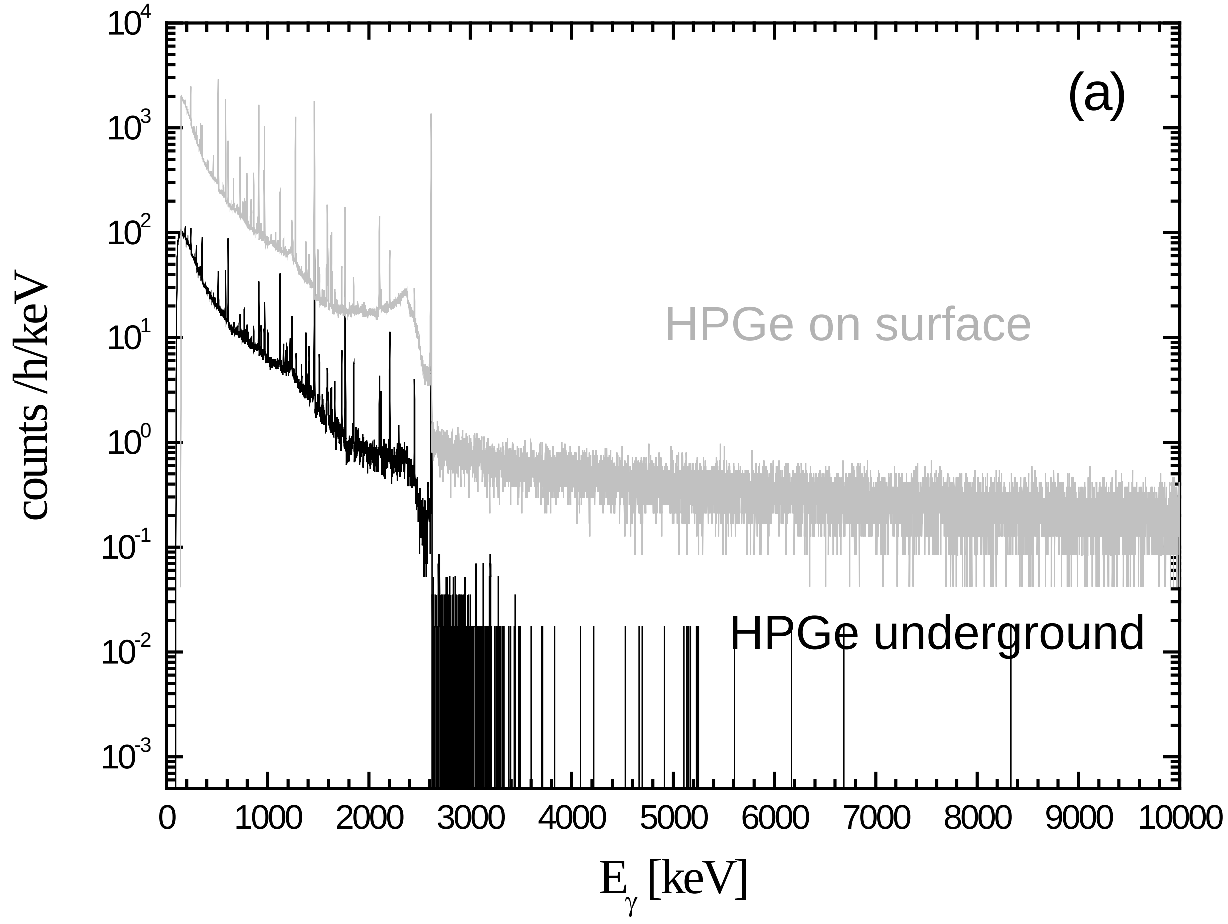


courtesy: A. Boeltzig

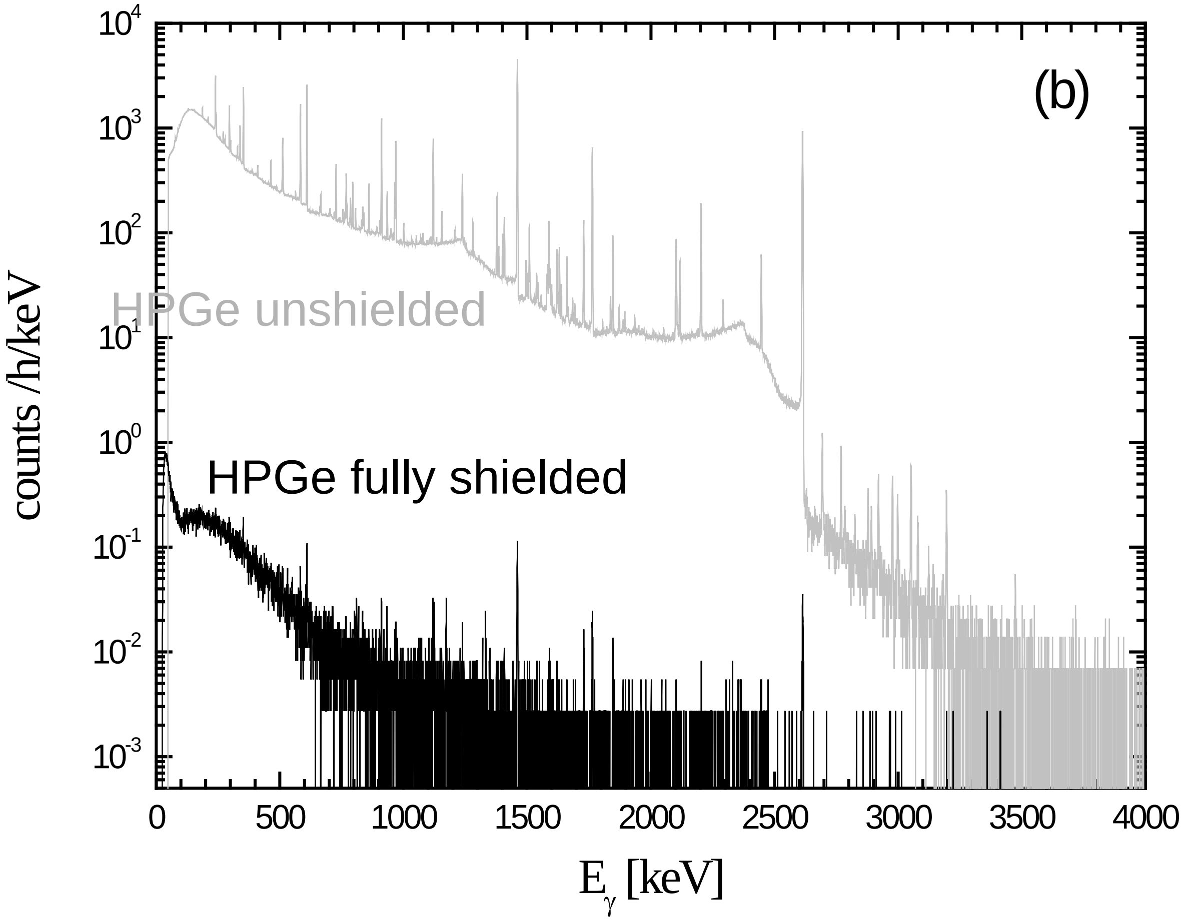
Benefit of an Underground Laboratory

in γ-ray spectroscopy

unshielded measurements

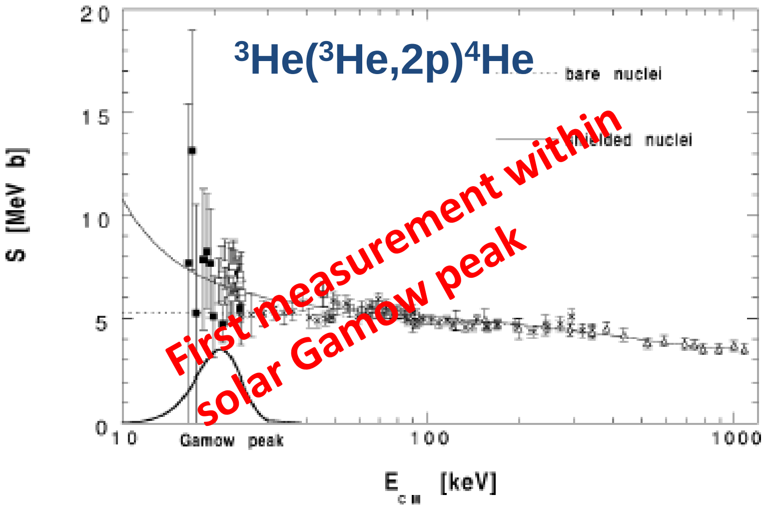


Measurement at LNGS



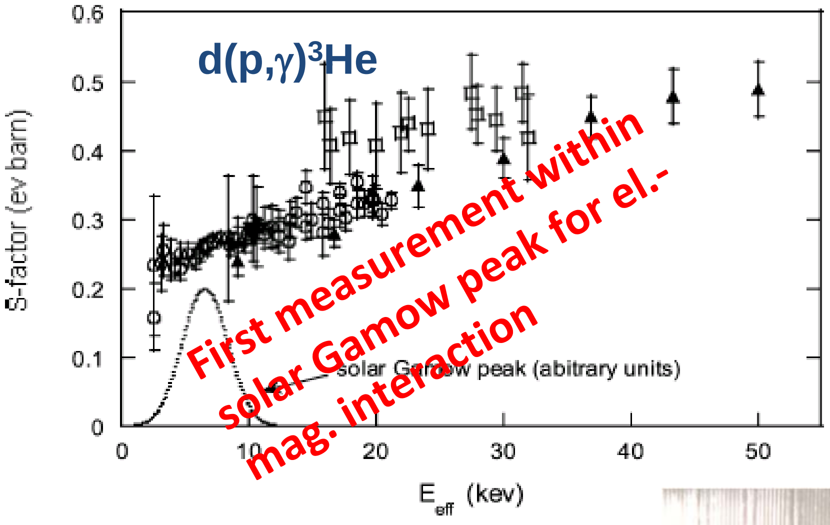
LUNA I – Achievements Underground

Two reactions (solar pp chain) already studied at Gamow energies:



at lowest energy: σ ~ 20 fb → 1 event/2 month

R. Bonetti et al.: Phys. Rev. Lett. 82 (1999) 5205



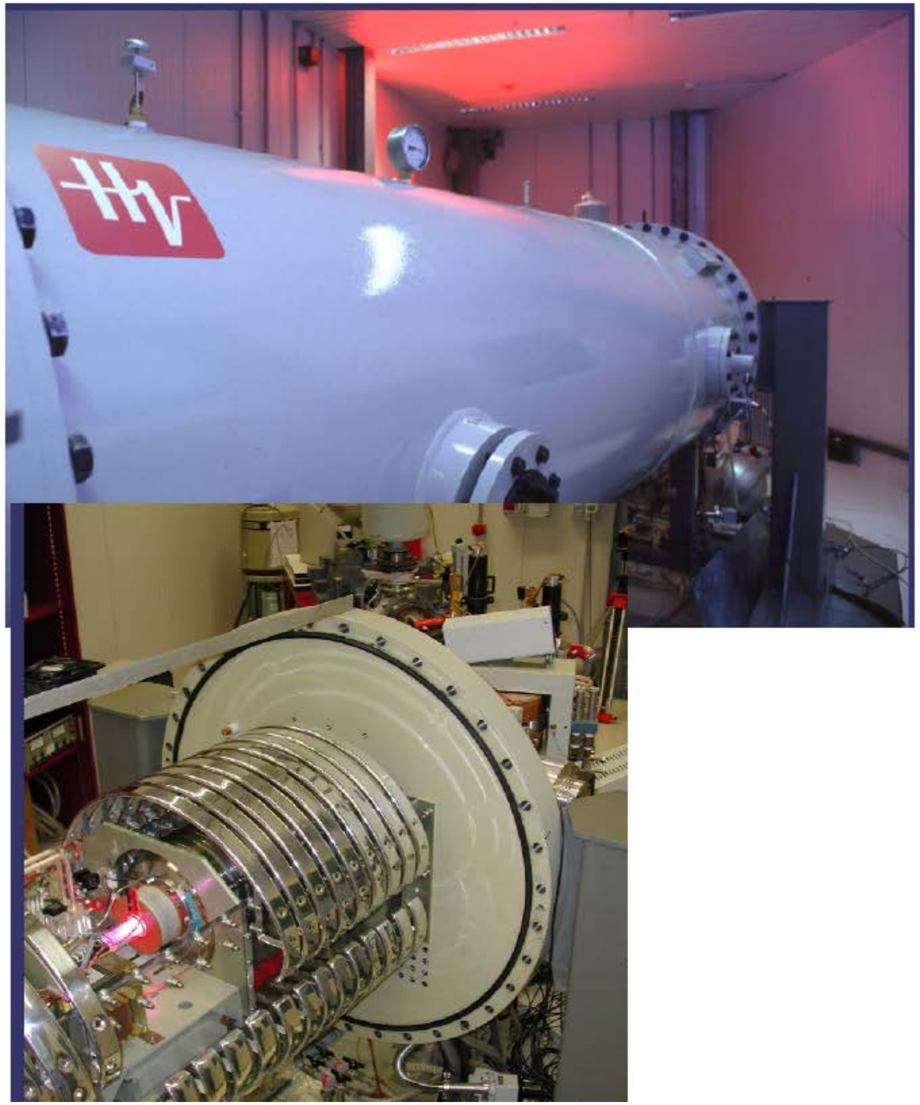
at lowest energy: σ ~ 9 pb → 50 counts/day

C. Casella et al.: Nucl. Phys. A706 (2002) 203

Definition of astrophysical S factor

$$\sigma(E) = \frac{S(E)}{E} \exp(-2\pi\eta)$$

LUNA II – 400 kV Accelerator (2000 – 2018(?))



$U_{terminal}$ = 50 – 400kV

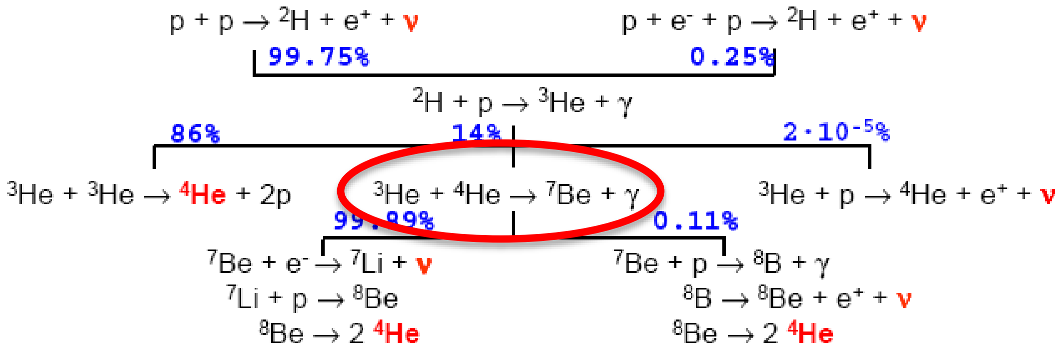
I_{max} = 500μA (on target)

ΔE = 0.07keV

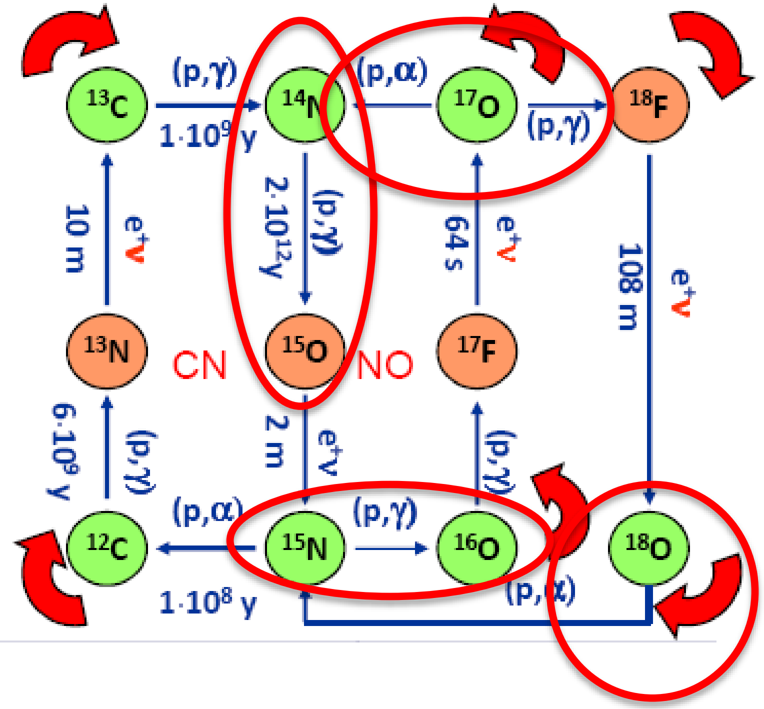
Allowed beams: H^+, ^4He, (^3He)

LUNA II – Key Studies

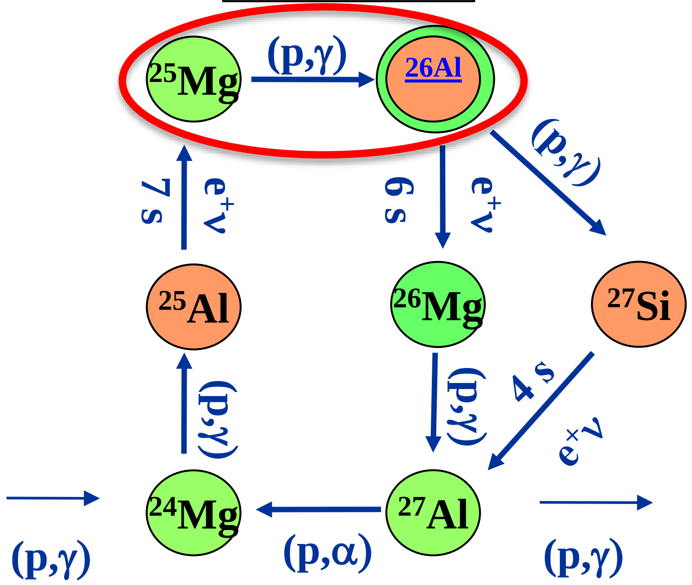
pp chain



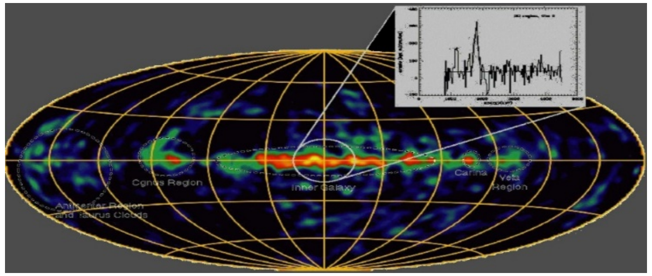
CNO cycle



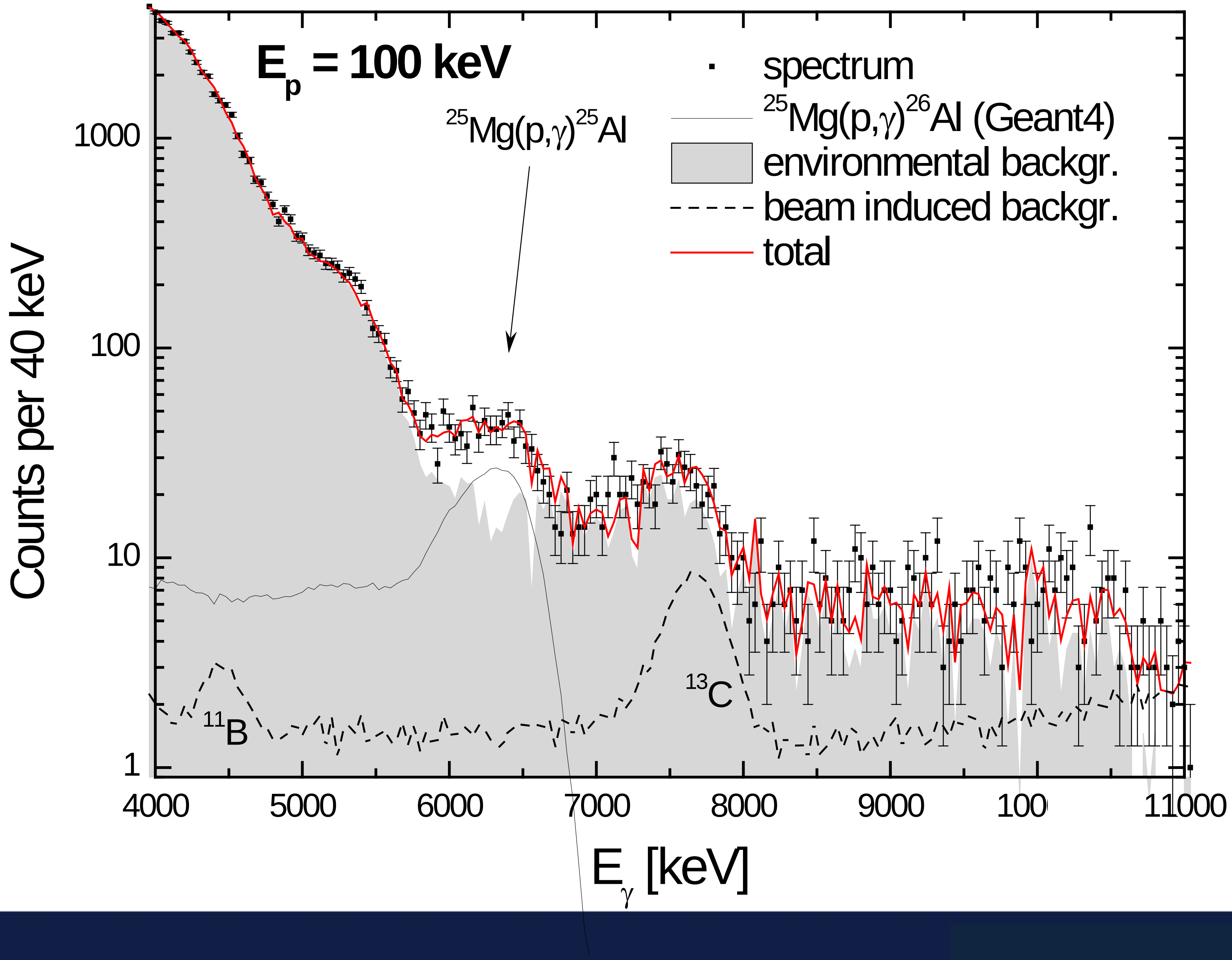
MgAl cycle



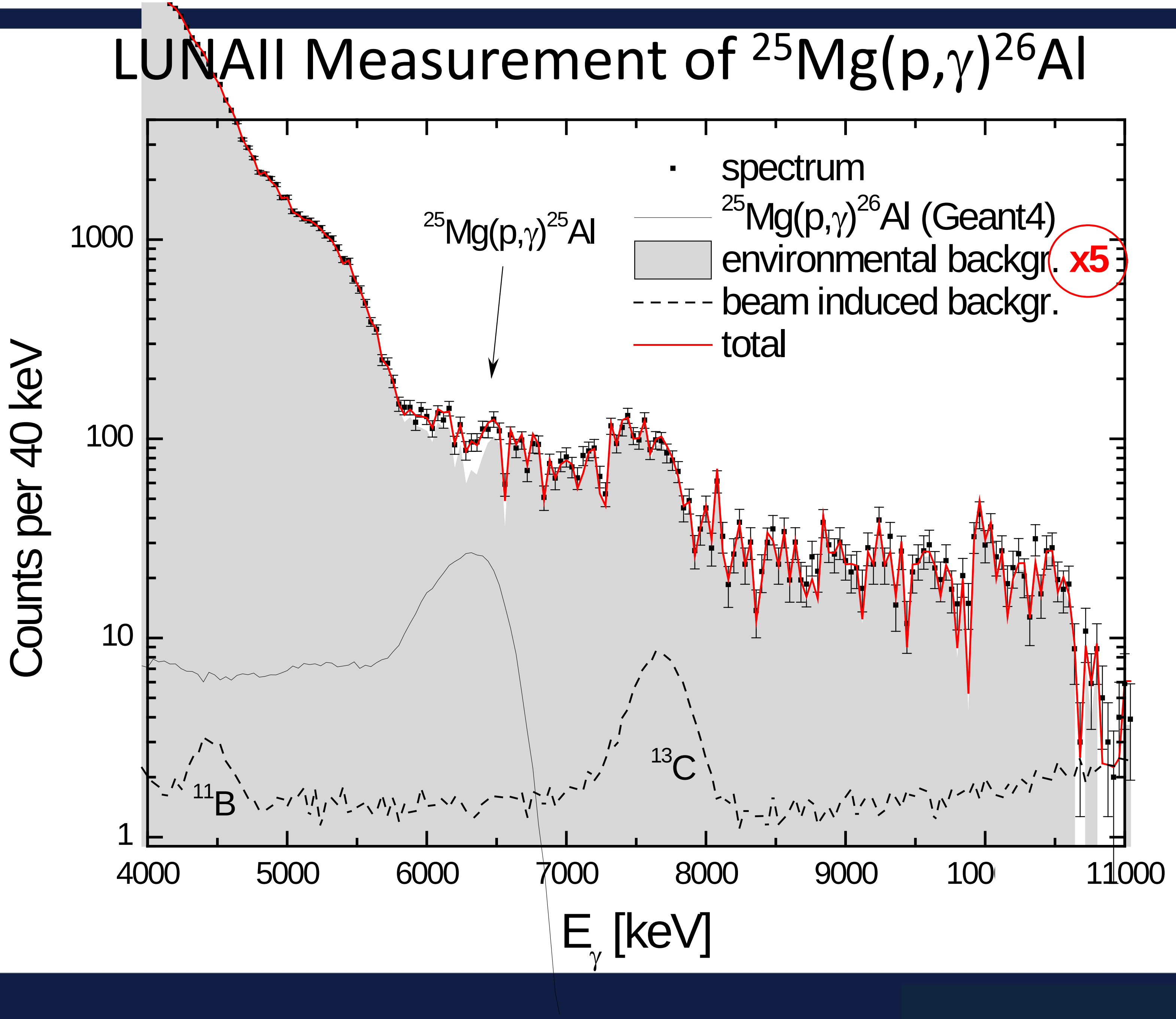
1.8 MeV ^{26}Al decay γ-ray line



LUNAII Measurement of $^{25}Mg(p,\gamma)^{26}Al$



LUNAII Measurement of $^{25}Mg(p,\gamma)^{26}Al$



Compact Accelerator System for Performing Astrophysical Research

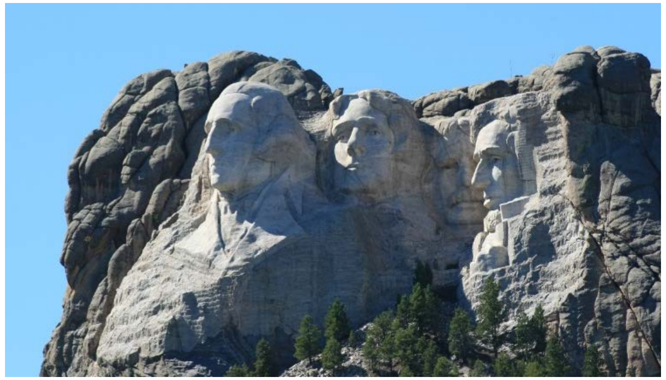
SOUTH DAKOTA
SCHOOL OF MINES & TECHNOLOGY

Frank Strieder (PI)
Tyler Borgwardt
Mark Hanhardt
Thomas Kadleczek
Chamaka Senarath
Brandon DeVries
Drew Powers

Dan Robertson (TC)
Manoel Couder
Michael Wiescher
Joachim Goerres
Axel Boeltzig
Bryce Frentz

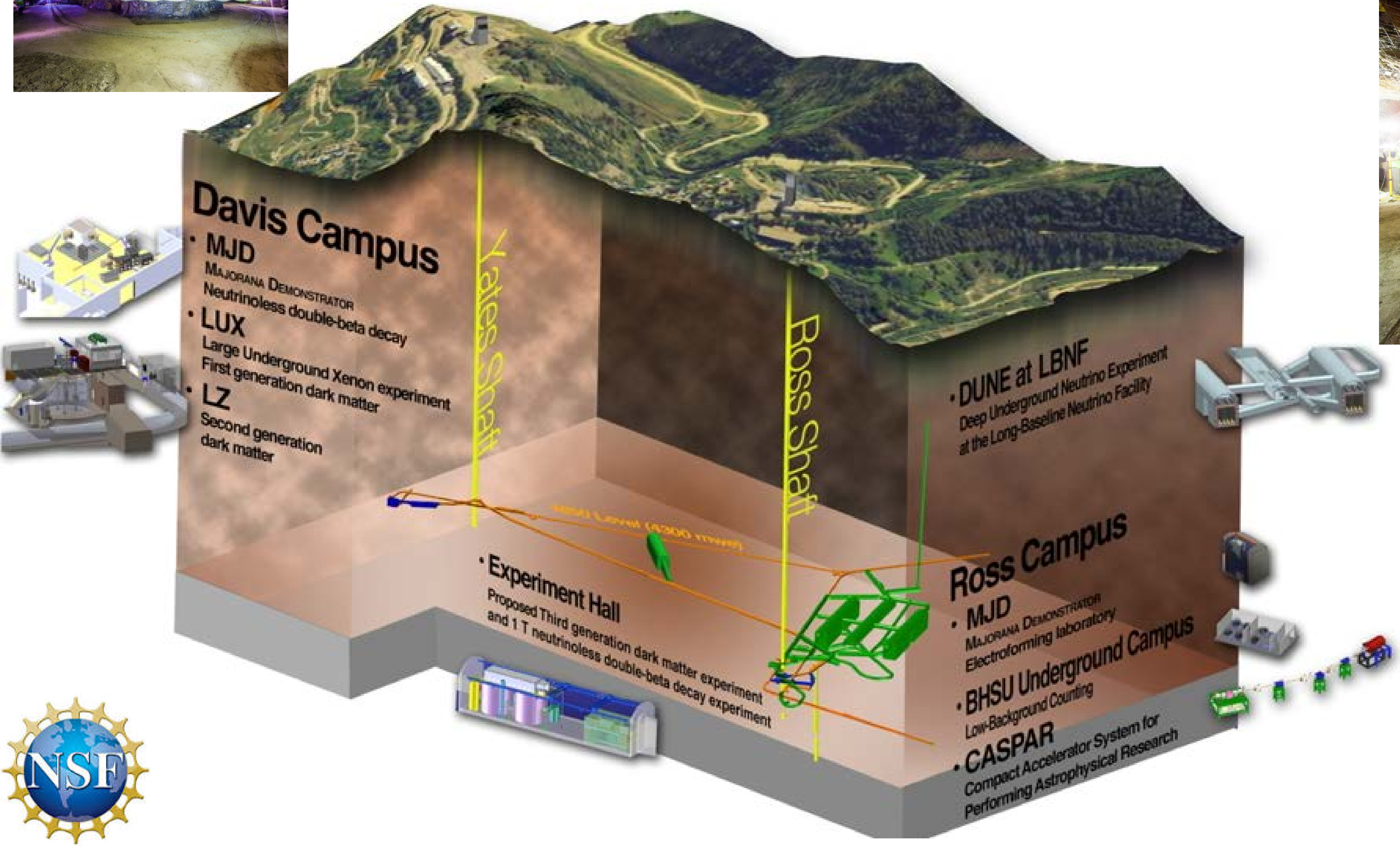
Uwe Greife

Sanford Underground Research Facility



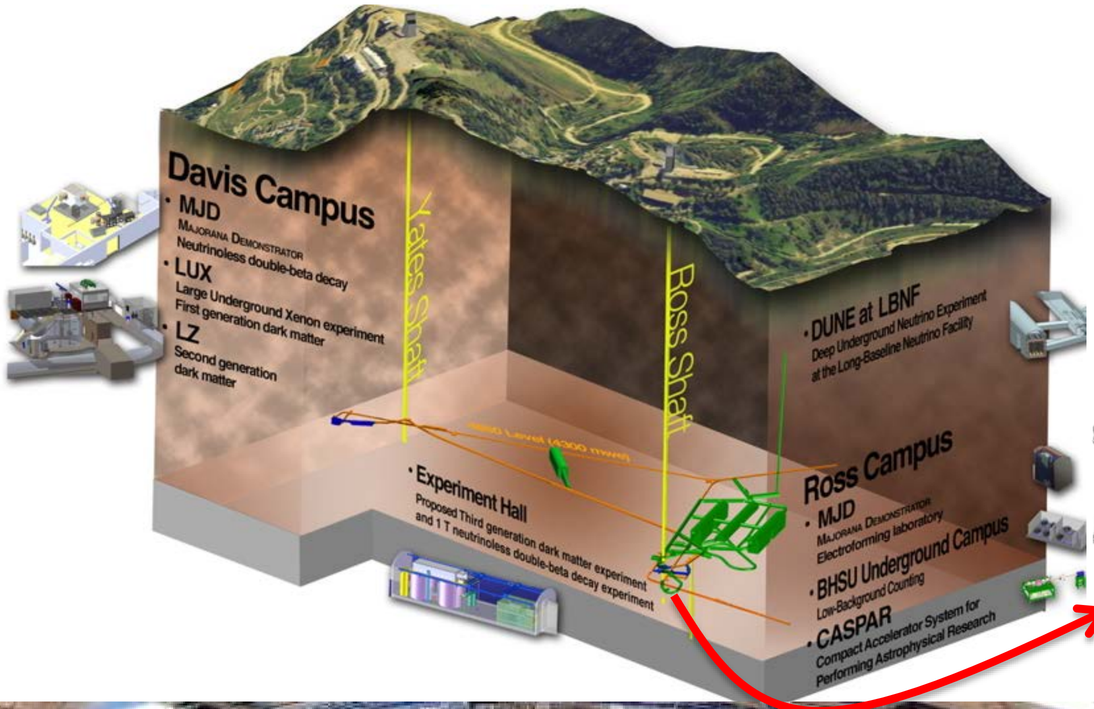
Sanford Underground Research Facility

Sanford Underground Research Facility

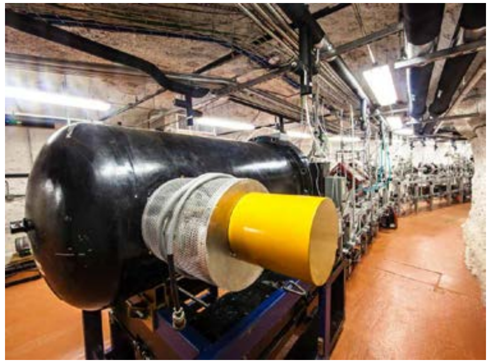


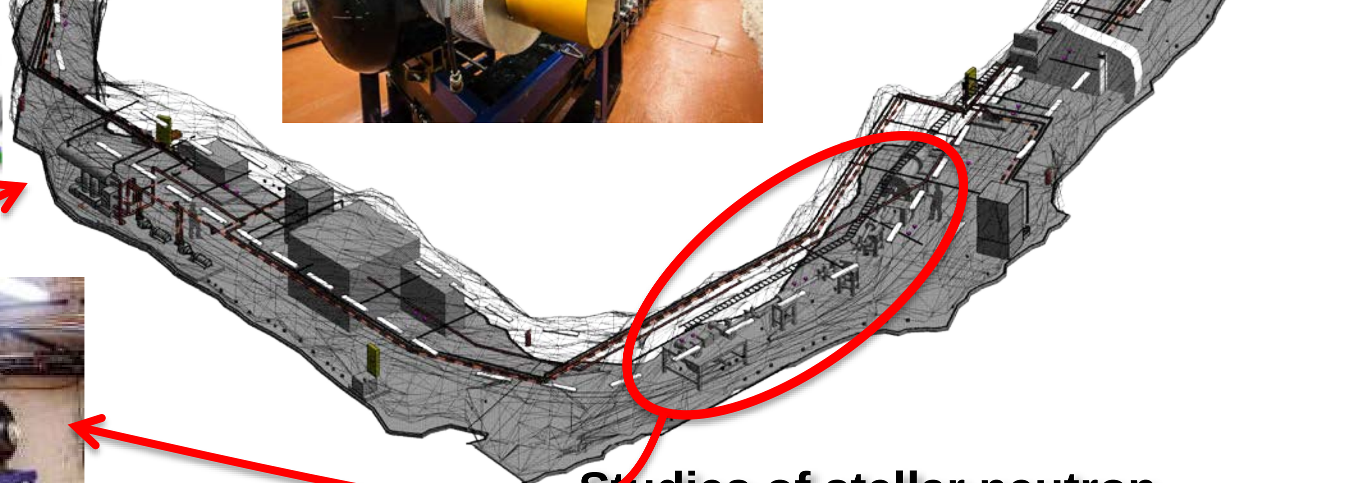
Compact Accelerator System for Performing Astrophysical Research

at Sanford Underground Research Facility



First US Underground Accelerator

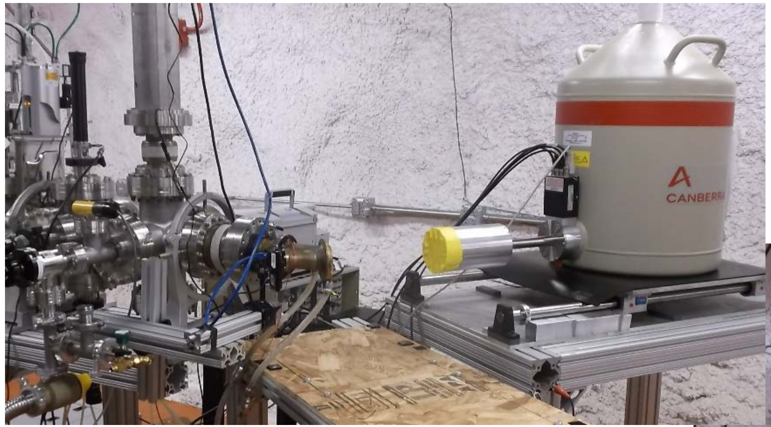




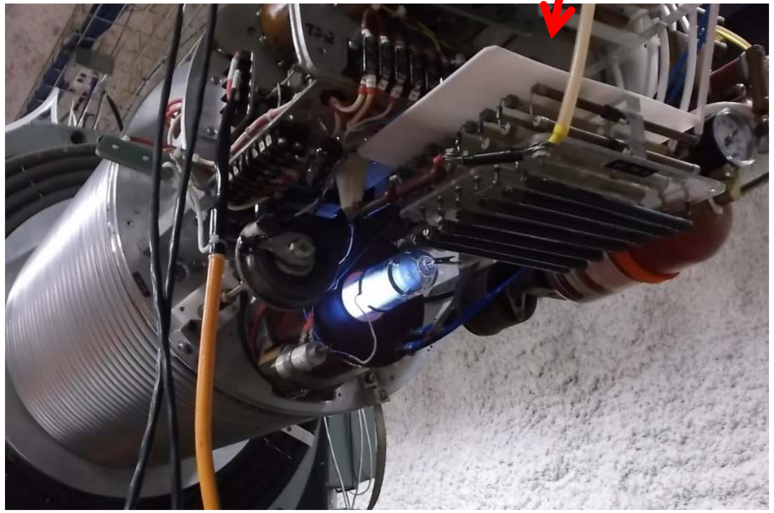
Studies of stellar neutron sources in the Laboratory
→ Understanding of Origin of the Elements

Accelerator - Model JN 1 MV van-de-Graaff with RF ion source

1 MV electrostatic accelerator:
- belt driven charging system
- positive ions - single stage
- particle intensity ~150µA



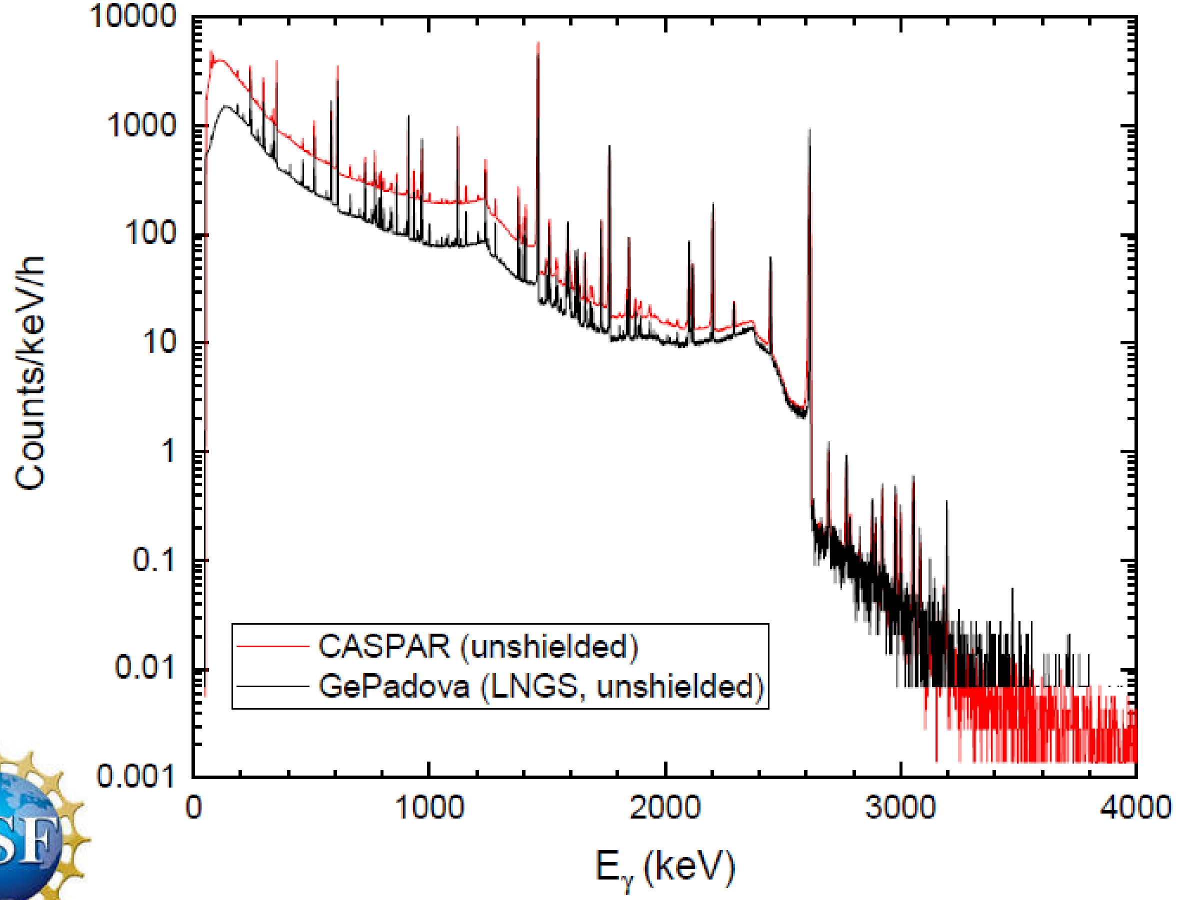
Exchangeable solid target
and windowless extended gas target
Roots blowers oil free pumps
& turbo molecular pumps



RF ion source
with helium plasma (usually closed in tank)

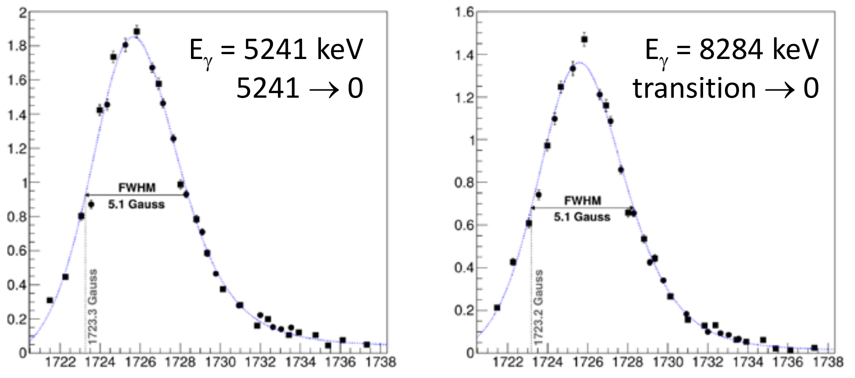
First Science at CASPAR

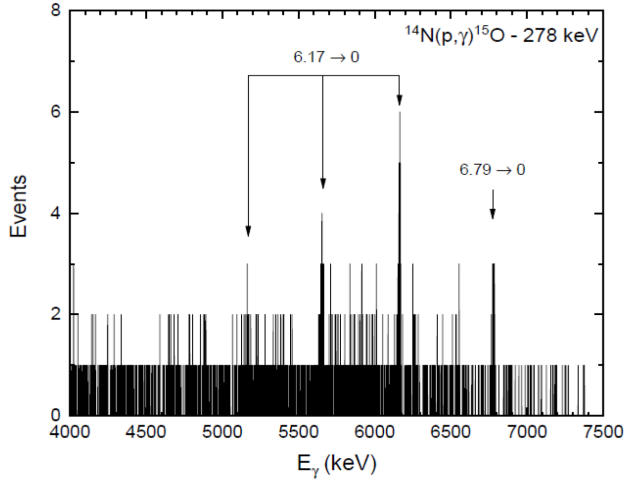
γ-ray background at CASPAR



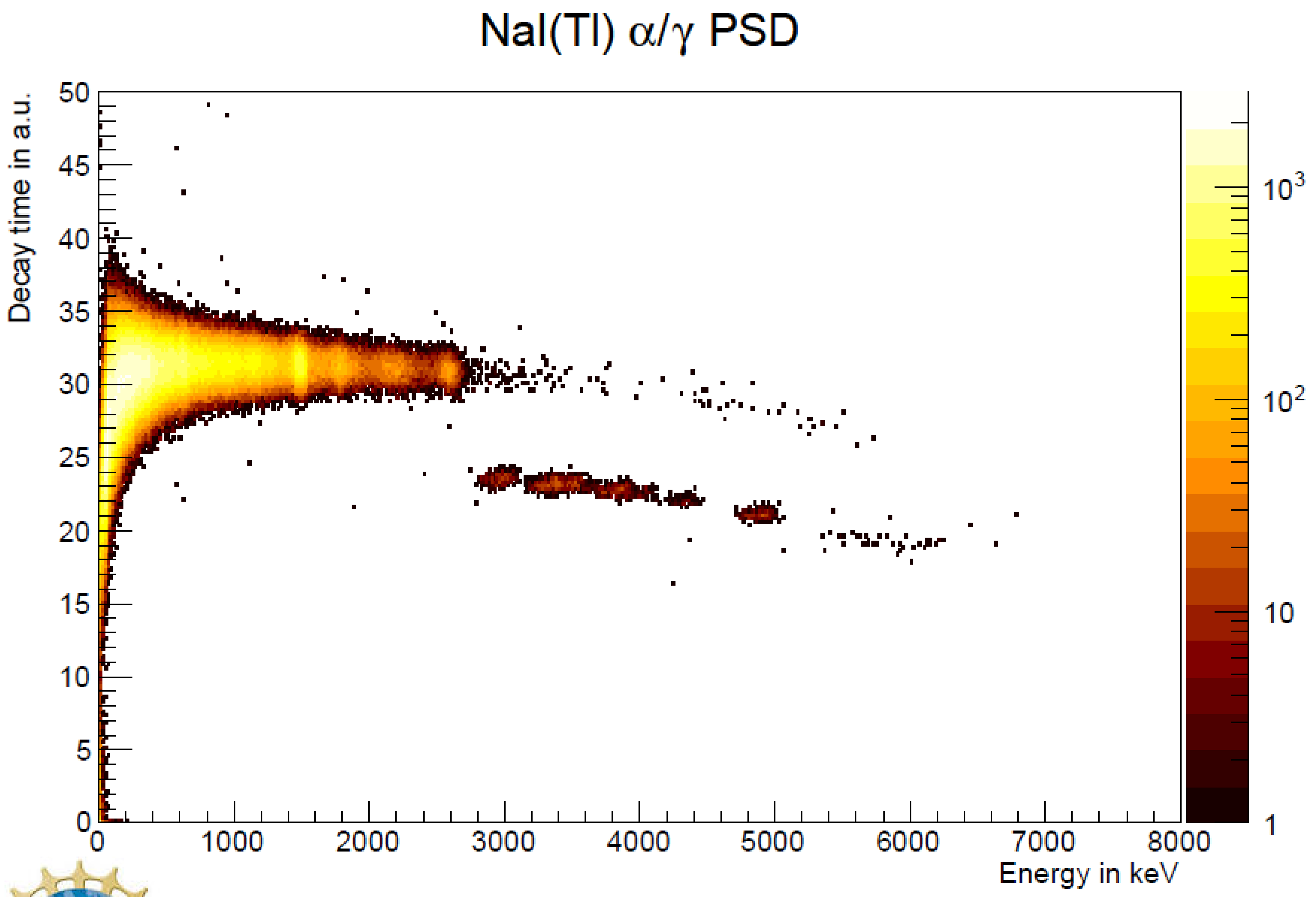
commissioning experiment

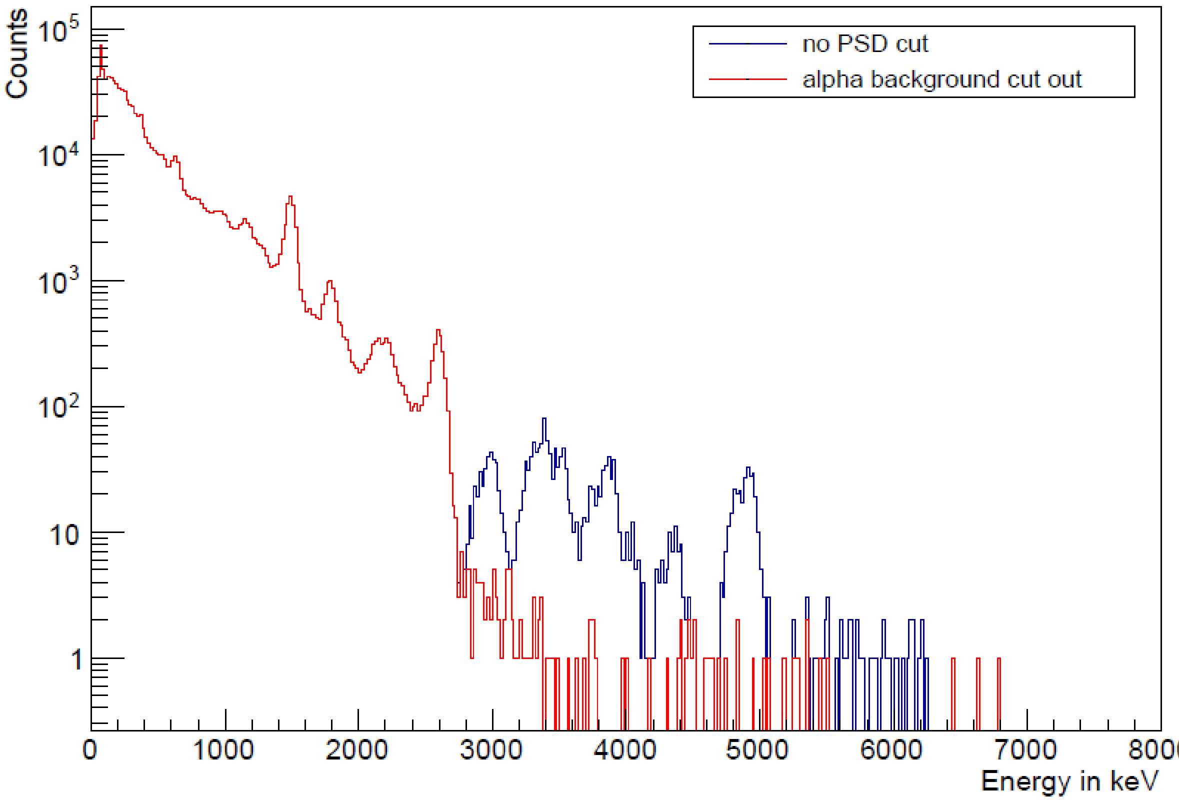
$^{14}N(p,\gamma)^{15}O$ at E_p = 1058 keV





First Science at CASPAR

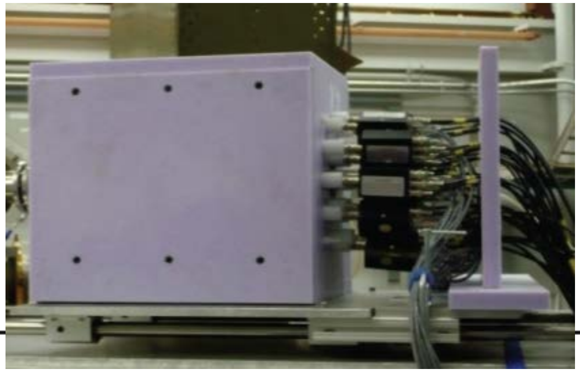


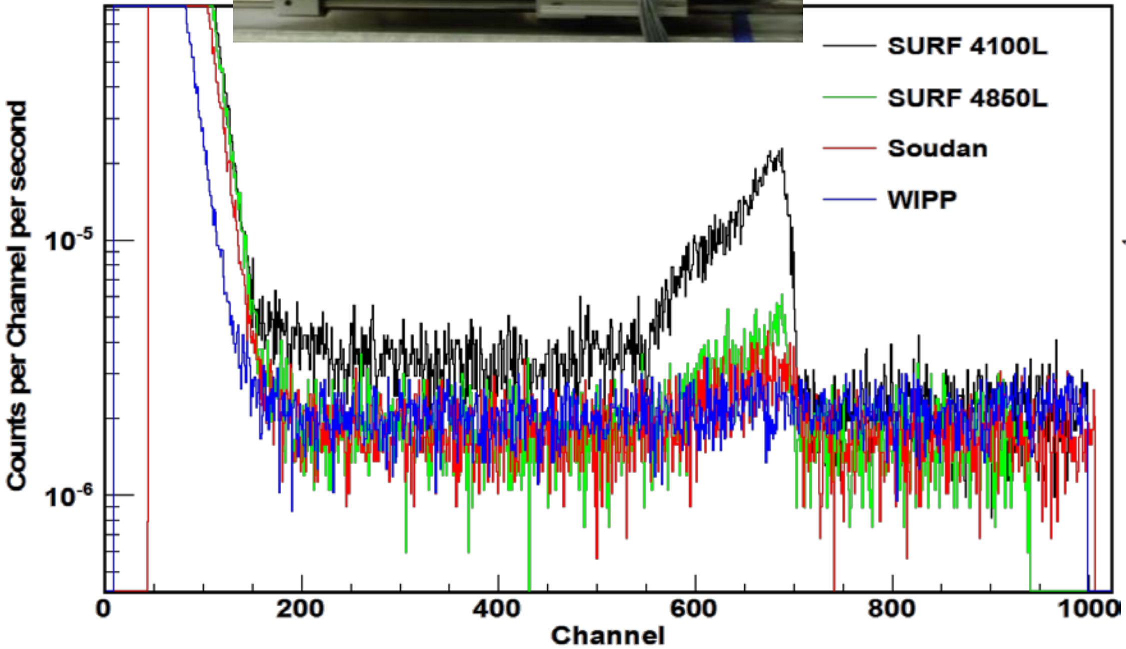


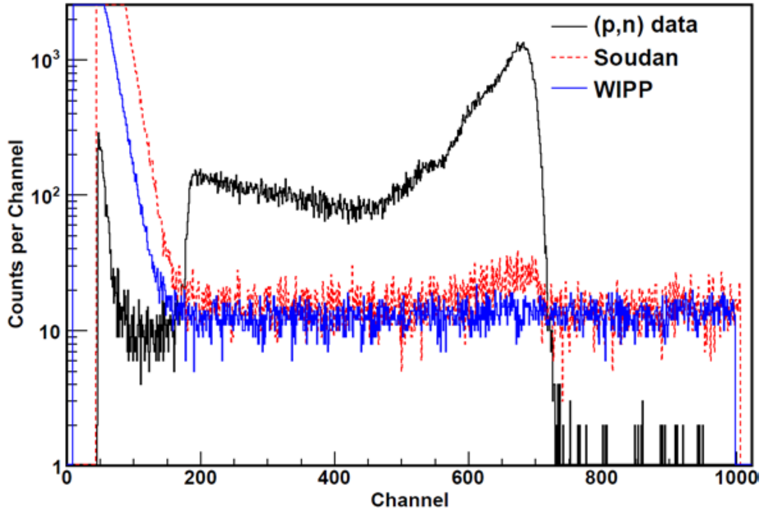
courtesy Axel Boeltzig

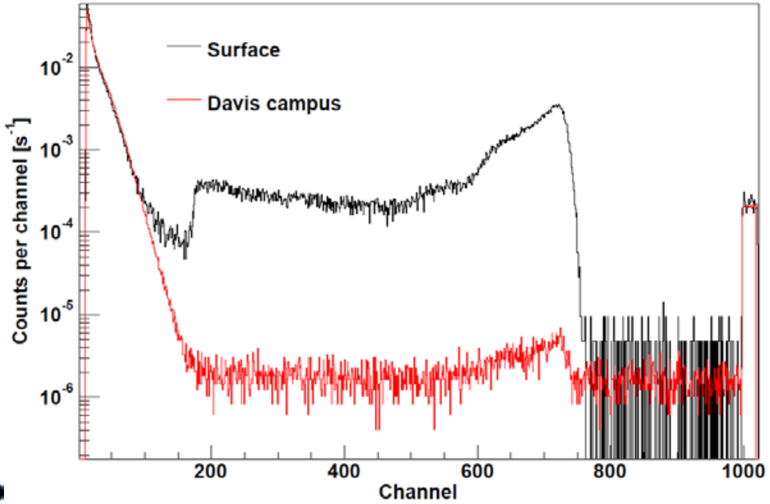
Neutron Background Reduction

^{3}He proportional counter in
a polyethylene moderator matrix





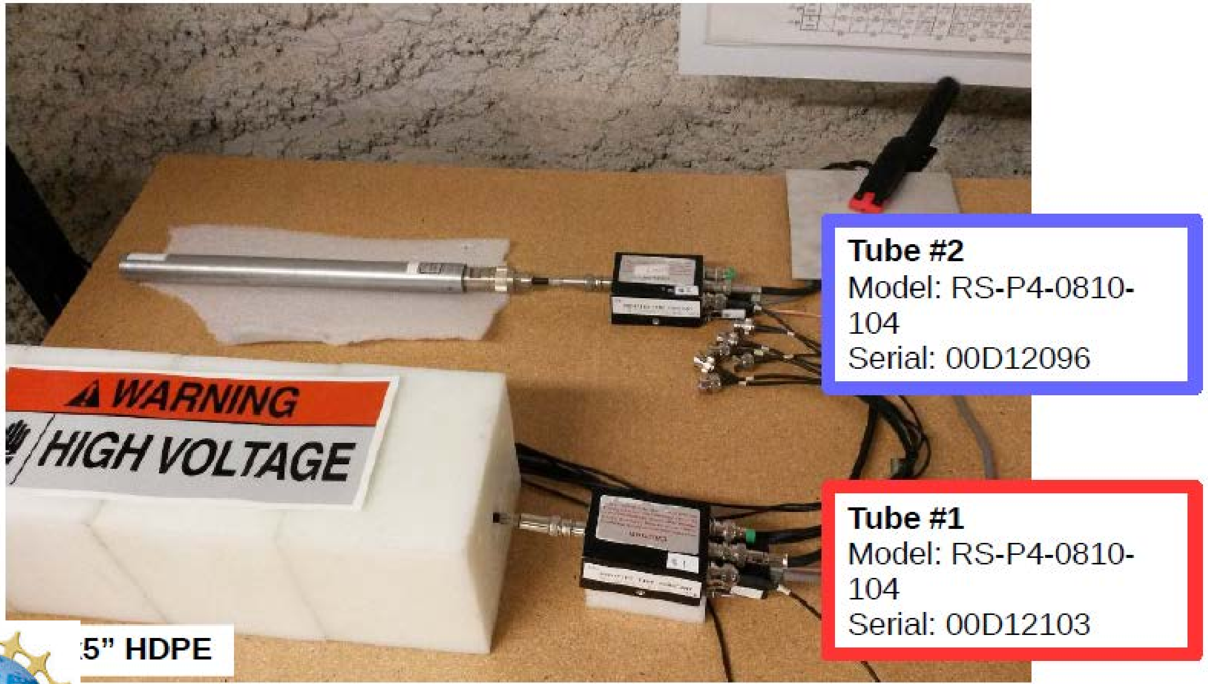


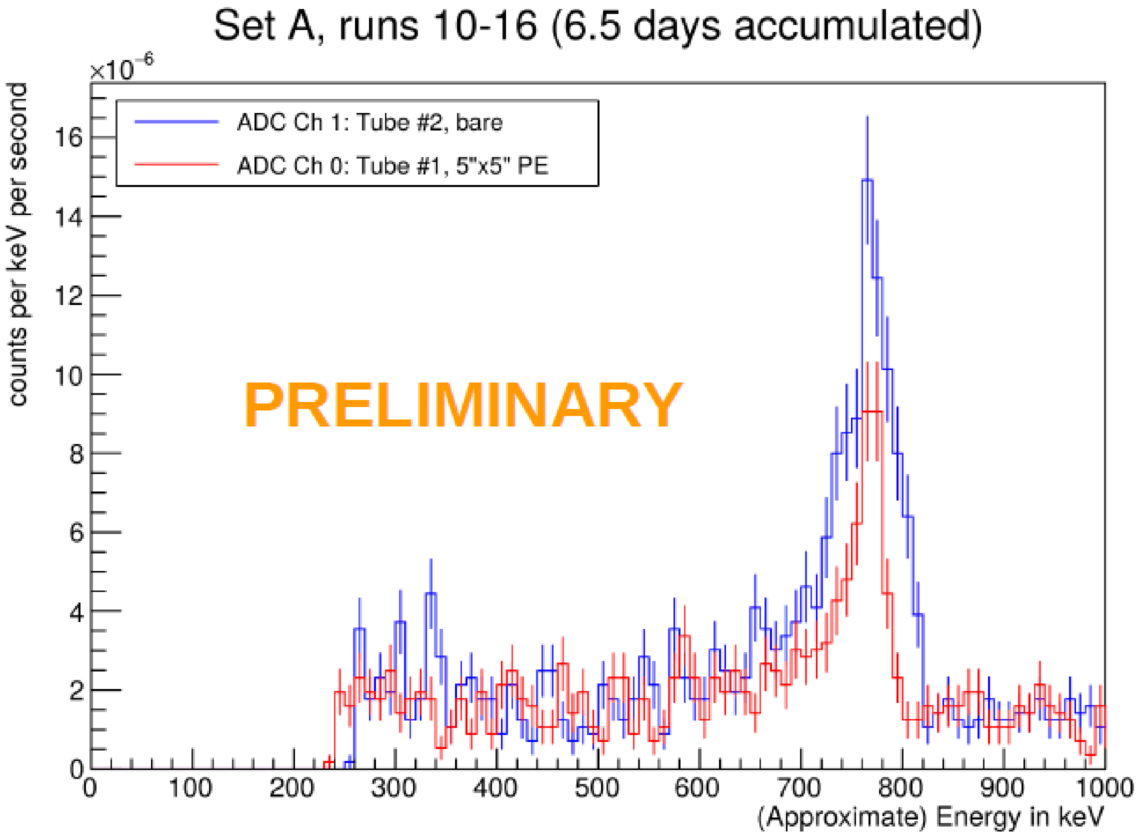


Neutron Background Reduction

On workbench in control room. Both detectors at +1400V (same HV supply).
Both preamplifiers with modified decay constants (100MOhm → 9MOhm in RC).

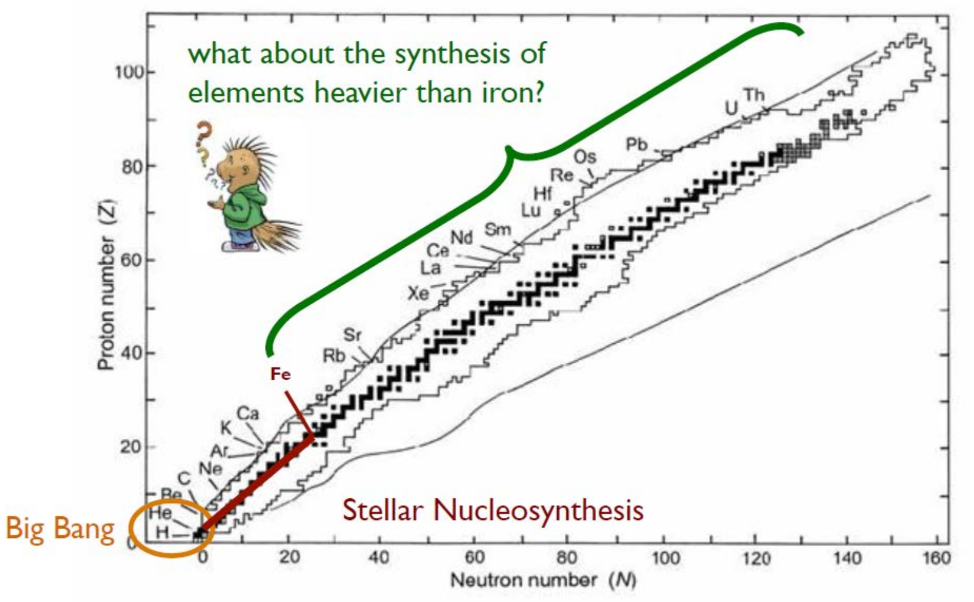
Preamp output digitized with CAEN N6730 (500MS/s), “standard firmware” (waveform acquisition, fixed trigger threshold.)





courtesy Axel Boeltzig

How were Elements from Iron to Uranium made?



"The 11 Greatest Unanswered Questions of Physics"
from: National Academy of Science Report, 2002

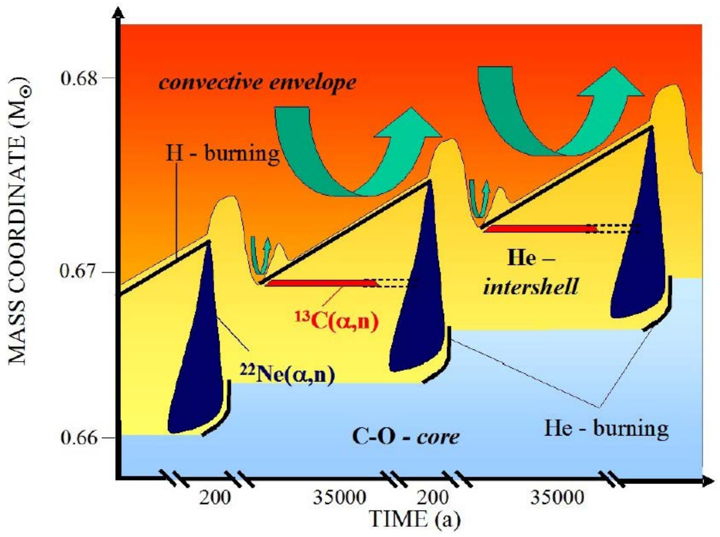
Main s-process: Thermally Pulsing AGB Stars

AGB star = Asymptotic Giant Branch star
= evolved star after central He burning

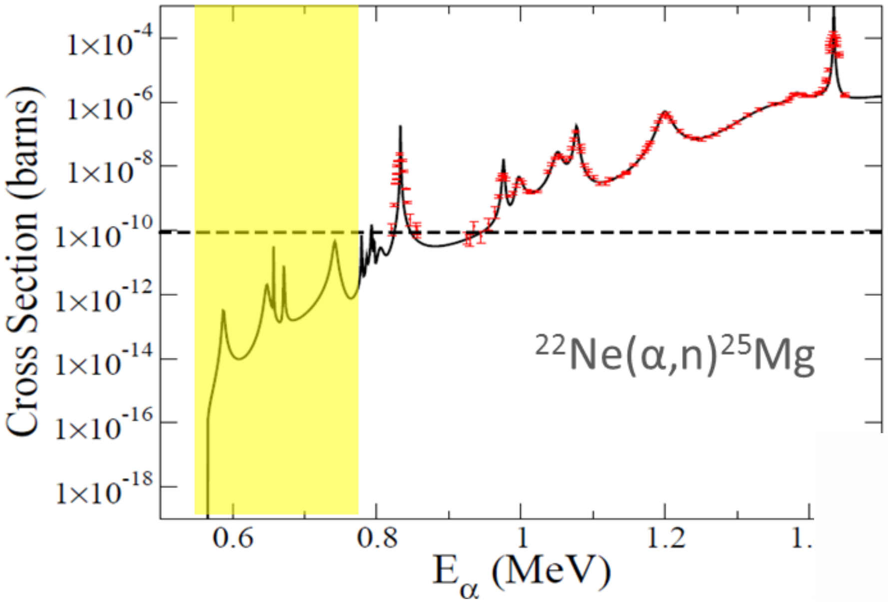
- neutron flux of $10^8 - 10^{11}$ n/cm^3 during different phases of pulsing
- neutron source strength critical

s- and r-process

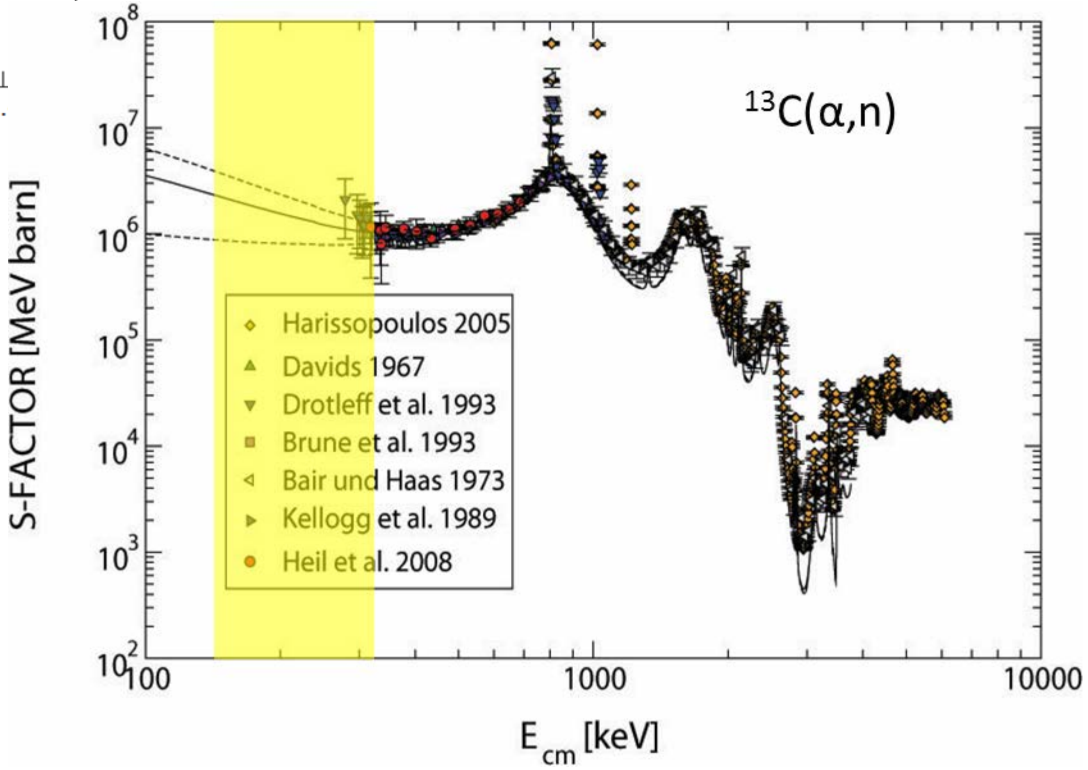
→ different astrophysical sites



Seeds for the s-process



- $^{22}Ne(\alpha,n)^{25}Mg$ and $^{13}C(\alpha,n)^{16}O$
- Neutron sources for the s-process
- Large Uncertainties in astrophysical energy region
- Measurements limited by cosmic-ray induced background



CASPAR Program: Currently 5-8 years

Some reactions of interest:

- $^{22}Ne(\alpha,n)^{25}Mg$
- $^{13}C(\alpha,n)^{16}O$

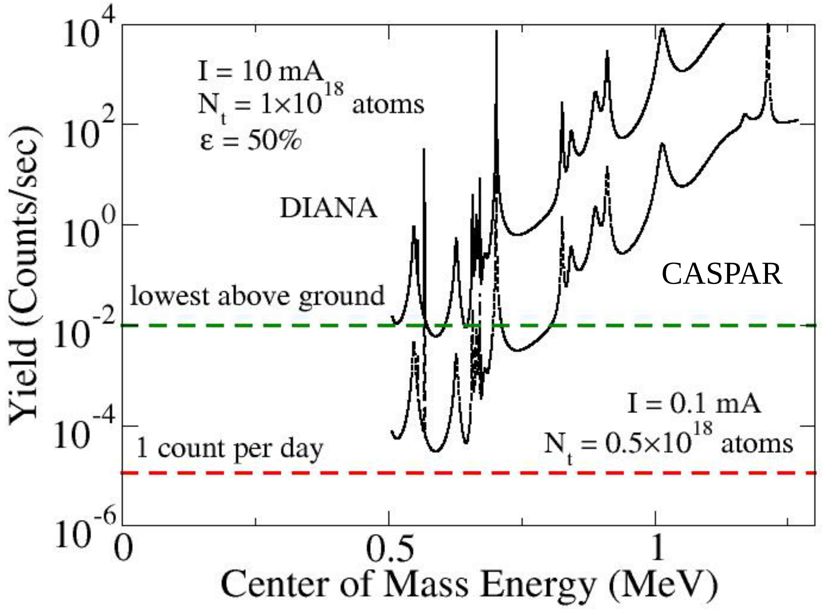
Priority

- $^{22}Ne(\alpha,\gamma)^{26}Mg$
- $^{14}N(p,\gamma)^{15}O$
- $^{3}He(\alpha,\gamma)^{7}Be$

γ-ray spectroscopy

- $^{26}Al(p,\gamma)^{27}Si$

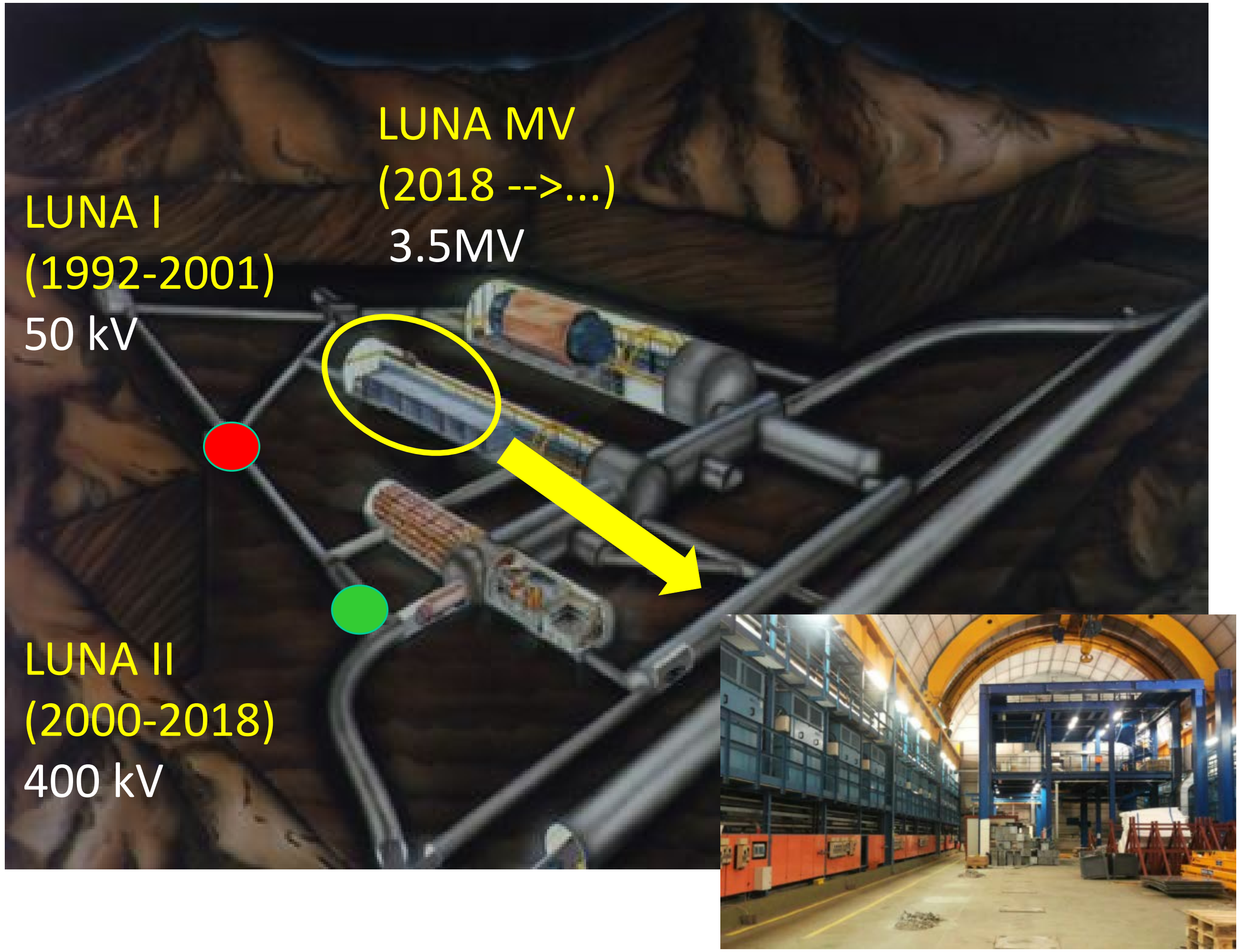
future challenges

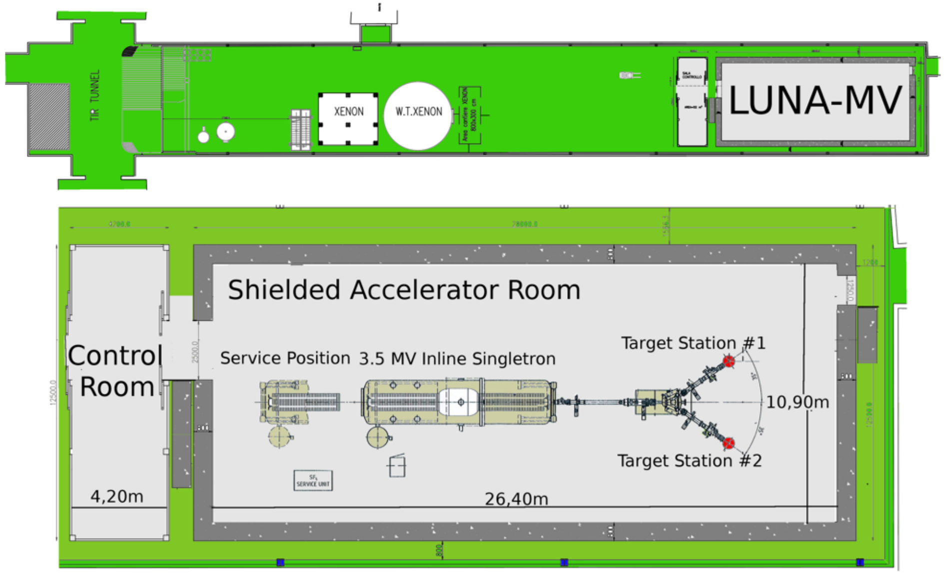


- Cavity rehabilitation and preparation completed
- Beneficial occupancy of accelerator vault August 2015
- First beam on target summer 2017
- First scientific results in 2018

LUNA MV project

LUNA MV will be installed in the North part of Hall B of LNGS





Funded by the Italian Department of Science as a “premium project”,
HVEE has been selected through a public tender as provider of the new accelerator (0.3 < TV < 3.5 MV) able to deliver intense H, He and C beams.

Expected installation at LNGS in 2019

courtesy Alba Formicola

LUNA MV- scientific program (2019 ….)

$^{12}C+^{12}C$: solid state target: gamma and particle detectors

$^{13}C(\alpha,n)^{16}O$: enriched ^{13}C solid or gas target. Neutron detector (data taking at LUNA 400 kV)

$^{22}Ne(\alpha,n)^{25}Mg$: enriched ^{22}Ne gas target. Neutron detector.

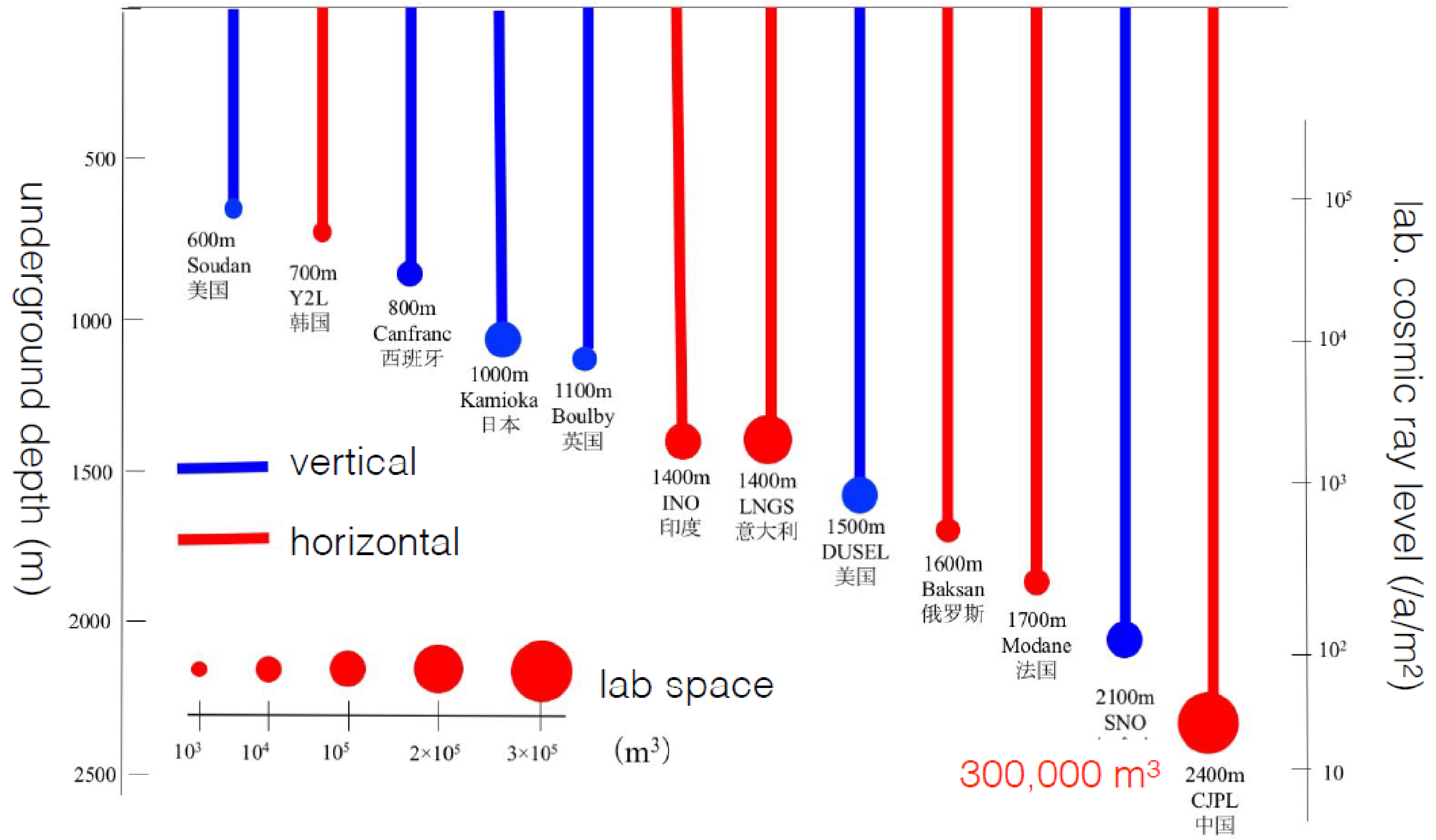
Commissioning measurement: $^{14}N(p,\gamma)^{15}O$
high scientific interest for revised data covering a wide energy range (400 keV - 3.5 MeV).

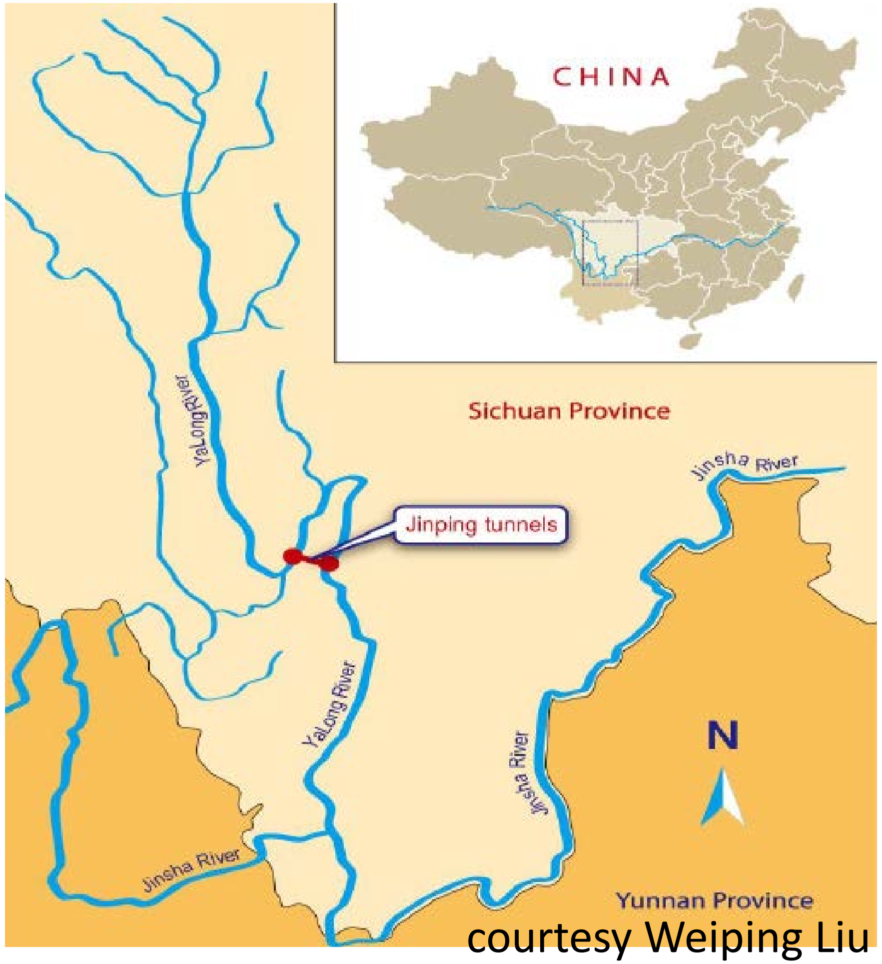
see the following talk by Paolo Prati and Andreas Best as well as poster session

courtesy Alba Formicola

China Jinping underground laboratory (CJPL)

comparison of underground labs



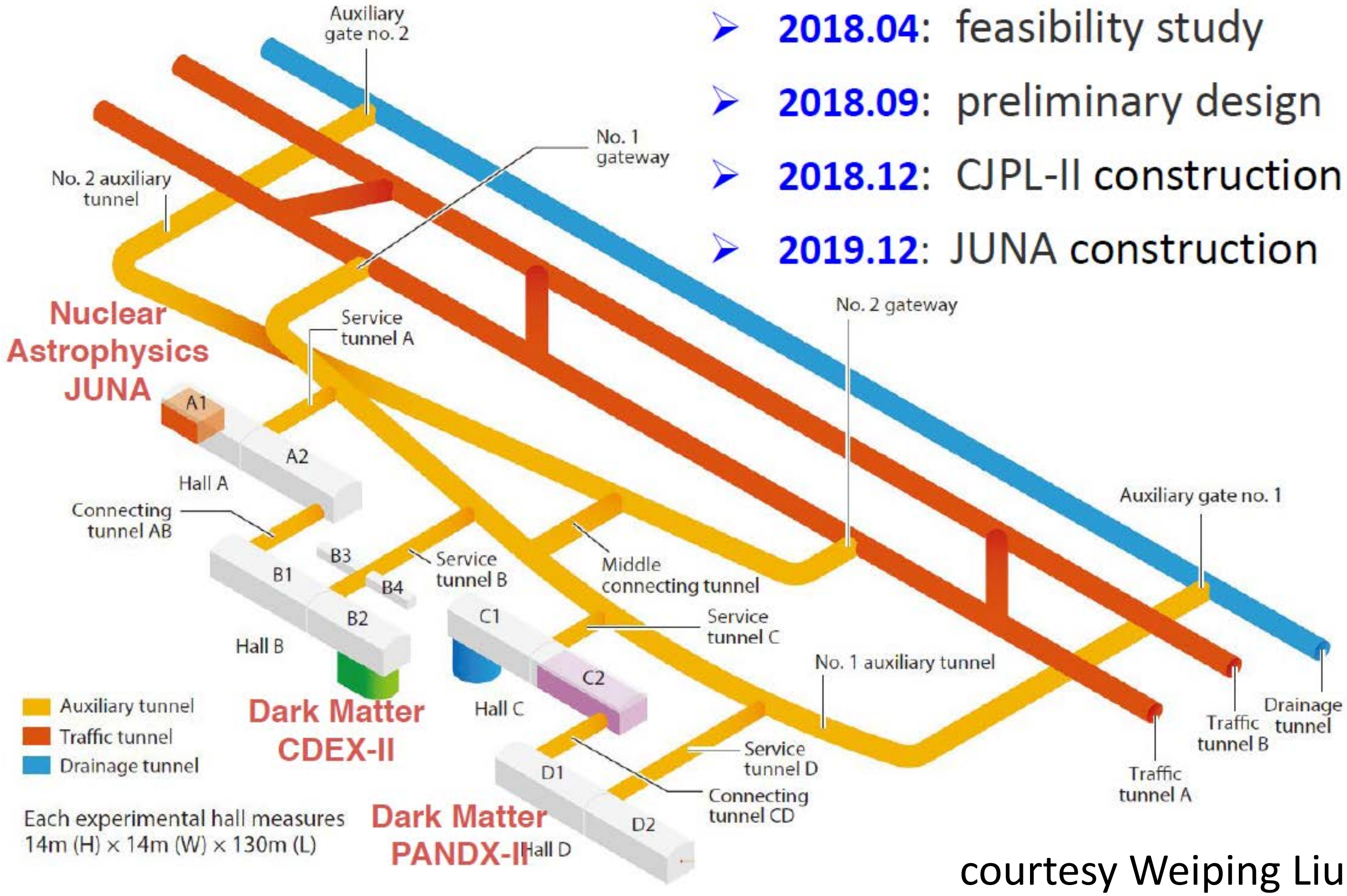


courtesy Weiping Liu

China Jinping underground laboratory （CJPL）

中国锦屏地下实验室
China Jinping Underground Laboratory
CJPL
清华大学 · 雅砻江流域水电开发有限公司

JUNA



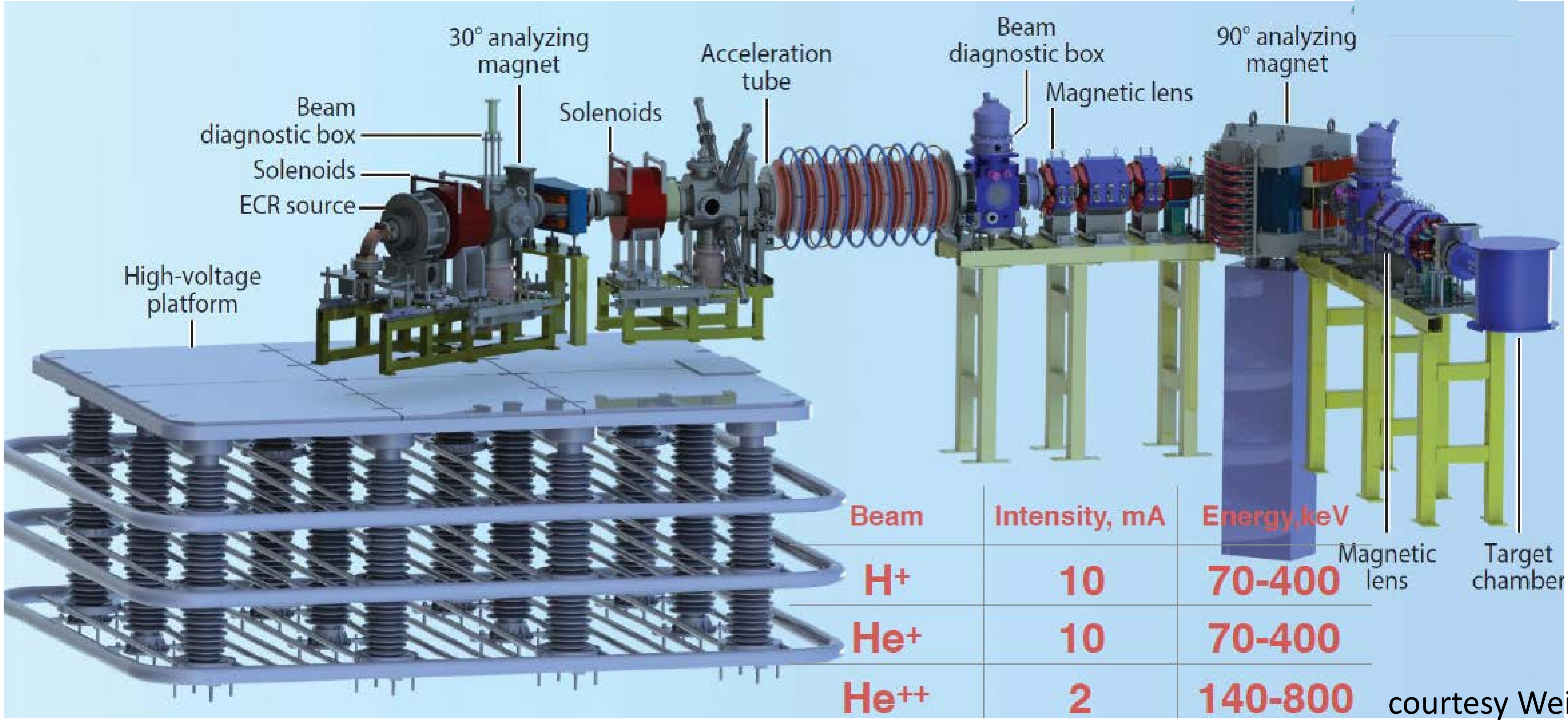
- **2018.04**: feasibility study
- **2018.09**: preliminary design
- **2018.12**: CJPL-II construction
- **2019.12**: JUNA construction

courtesy Weiping Liu

中国锦屏地下实验室
China Jinping Underground Laboratory
CJPL
清华大学 · 雅砻江流域水电开发有限公司

China Jinping underground laboratory （CJPL）

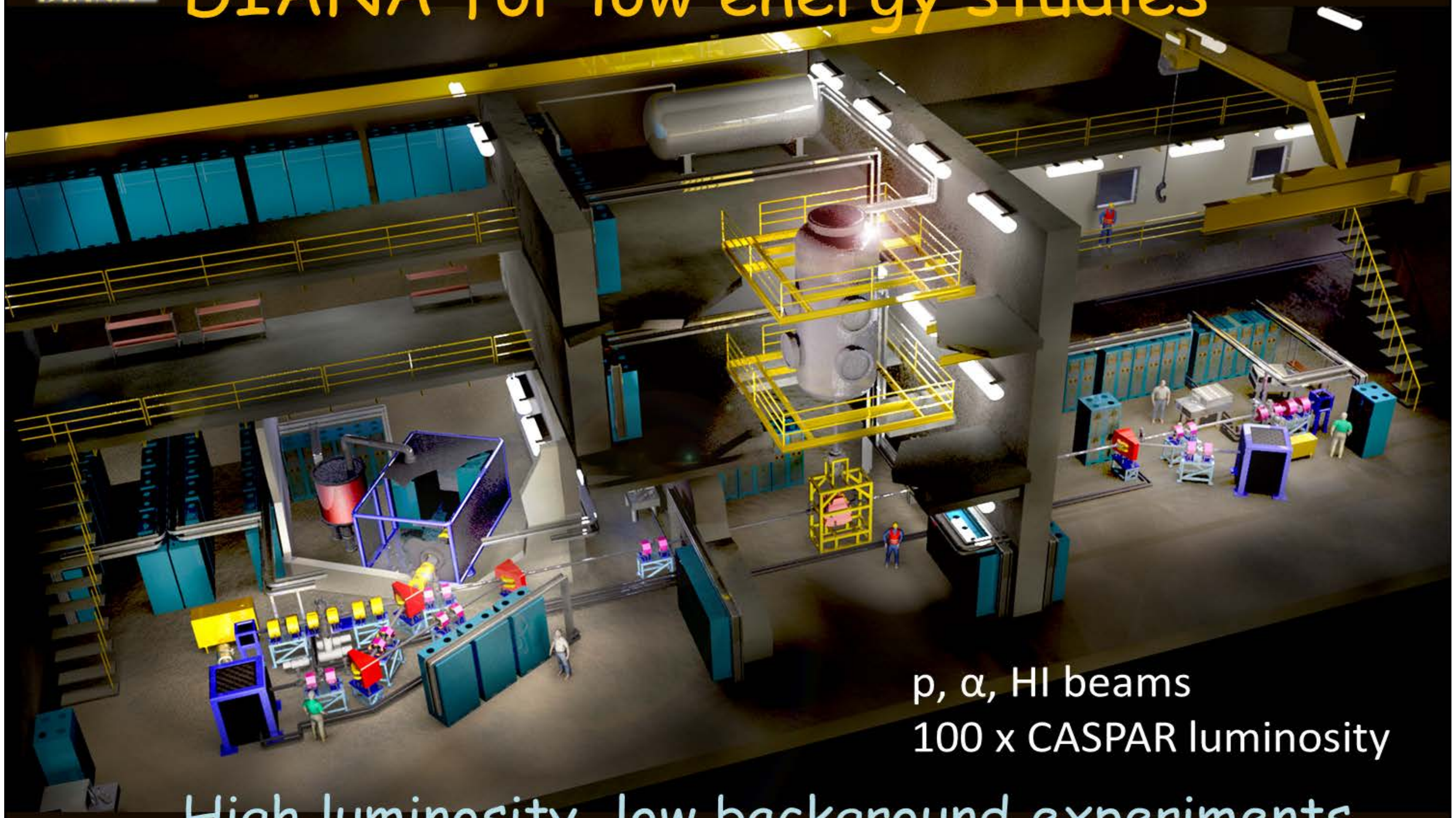
JUNA



Beam	Intensity, mA	Energy,keV
H^+	10	70-400
He^+	10	70-400
He^{++}	2	140-800

courtesy Weiping Liu

Underground accelerator project DIANA for low energy studies



High luminosity, low background experiments


Thank you for your attention!